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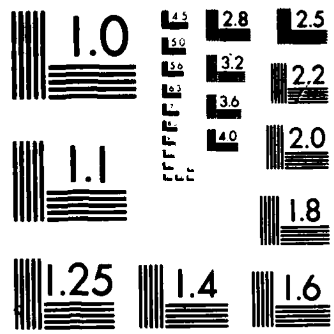

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STATE-OF-THE-ART FOR ASSESSING EARTHQUAKE HAZARDS IN THE UNITED STATES

Report 24

WES RASCAL CODE FOR SYNTHESIZING EARTHQUAKE GROUND MOTIONS

by

Walter J. Silva

with program coding by

Kin Lee

Woodward-Clyde Consultants
Walnut Creek, CA 94596-3564

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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A computer code (RASCAL) has been developed to provide realistic predictions of ground motion parameters for applications to earthquake engineering risk assessment. The code incorporates random vibration theory (RVT) to calculate peak value of acceleration and velocity in addition to response spectra for specified earthquake source and propagation path parameters (Boore, 1983). To generate synthetic time histories, the code combines the phase spectra from observed strong motion records to a theoretical Brune (1970, 1971) modulus. In addition, the above techniques are employed to produce an acceleration time history whose response spectrum matches a specified target or design response spectrum.

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PREFACE

This report was prepared by Dr. Walter J. Silva of Woodward-Clyde Associates, Walnut Creek, California, under Contract No. DACW39-85-M-1585. Program coding for the report was done by Mr. Kin Lee of Woodward-Clyde. The study is part of ongoing work at the US Army Engineer Waterways Experiment Station (WES) in the Civil Works Investigation Study, "Earthquake Hazard Evaluations for Engineering Sites," sponsored by the Office, Chief of Engineers (OCE), US Army.

Preparation of this report was under the direct supervision of Dr. E. L. Krinitzsky, Engineering Geology and Rock Mechanics Division (EGRMD), Geotechnical Laboratory (GL), WES, and the general supervision of Dr. D. C. Banks, Chief, EGRMD, and Dr. W. F. Marcuson III, Chief, GL.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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CONTENTS

1.0 INTRODUCTION

In either a deterministic or probabilistic seismic hazard evaluation an essential element is a description of the variability of ground motion parameters with distance (or depth) and earthquake size or magnitude. Once a distance and design basis earthquake is decided upon, the region specific attenuation relation is then utilized as an estimator to predict, with associated variance, the ground motion parameters to be expected at the site. If attenuation relations are available which parameterize peak values and frequency content through the response spectra, then the exposure is reasonably well specified. If however, only peak values are constrained by the attenuation relation, these may be utilized to scale an assumed frequency dependence via an adopted response spectrum shape. While not as satisfying as a region specific response spectrum shape, the adopted shapes are based upon many observations and can be adjusted to relect the magnitude range contributing to the seismic hazards.

The representation of the design ground motions by a response spectrum is sufficient for the seismic design evaluations of most engineered structures (e.g. commercial buildings, hospitals, etc.). However, for large, complex and/or critical facilities, time history analyses are often necessary, especially when there is significant non-linear structural response (e.g. earth dams, offshore platforms, etc.). For these evaluations, one or more accelerograms are selected whose response spectrum match the design spectrum in some average sense.

In regions of high seismicity rates which have had established strong motion instrumentation programs for a period of time, a sufficient data base of observations may be available to provide representative accelerograms and to constrain regression analyses for peak values and response spectra. While the range of magnitudes and distances is always less than ideal, definite trends may be characterized statistically so that extrapolations may be made with some level of confidence in not only the values themselves but also the degree of conservatism as well.

Time histories, which are consistent in amplitude, duration, and frequency content with observational data are generated through filtering noise samples (Nau et al., 1982) or by splicing together selected portions of observed time histories. Also, response spectral matching techniques may be applied to empirical data which scale, through filters, the time history (Tsai, 1972). This results in a time history whose response spectra is close to the design response spectrum.

Although these approaches retain the frequency, amplitude, and duration characteristics in a statistical sense, they usually produce time histories which could not have resulted from any earth process. The resulting velocity and displacement time histories from the artificially generated accelerograms are often inconsistent with observed motions, a fact that may be essential in response calculations for longer period structures. These approaches have evolved through necessity and employ little knowledge of earthquake source processes or wave propagation physics.

At the other extreme in ground motion prediction, detailed descriptions of source properties (e.g. location, direction, rupture velocity, distribution of asperities or barriers, and rise times) and propagation path parameters are utilized to generate synthetic time histories (Heaton and Helmberger, 1978, Apsel et al., 1983). These models are essential to understand past seismic events and they can be utilized to predict future ground motions. However, they require the specifications of source details and path effects which can have profound effects on the predicted ground motion. Generally, a range in parameters is utilized in a sensitivity analysis which translates into uncertainties in the predicted motion.

The modeling approach has recently attempted to accommodate, in a natural way, some of the stochastic aspects of source processes and path effects by utilizing small, well recorded events as a basis to construct time histories (Hartzell, 1978). The observed events are scaled and summed, utilizing source physics, to model time histories for large events (Hadley

and Helmberger, 1980; Kanamori, 1979). This hybrid approach is very attractive in that aspects of both source and path complexities are incorporated. This reduces somewhat the arbitrary nature in parameter specification and allows more definitive calibrations with large events to help constrain the remaining variables.

An extremely important application of the hybrid approach is its utility in providing guidelines in extrapolations. Estimates of ground motion parameters using various empirical models (Donovan, 1973; Idriss, 1978; Joyner and Boore, 1981; Campbell, 1981; Joyner and Boore, 1982; Joyner and Fumal, 1984) differ little in regions of distance and magnitude where data are abundant. However, in regions where extrapolations are required, close to moderate and large earthquakes, the differences can be large. The differences are due primarily to the mathematical form chosen to parameterize the data. In these regions, the careful use of modeling which is based upon observational data can be a powerful tool in assessing the conservatism of extrapolated empirical relations (Hadley and Helmberger, 1982). The modeling is calibrated in regions where data exist by parameter variation and sensitivities are assessed. A level of confidence is achieved, at least by the modelers, and estimates are made on ground motion which may guide or give confidence in extrapolated empirical relations.

While the above techniques are the basic tools in ground motion estimation, they are both fundamentally based upon observational data. The empirical approach obviously cannot be utilized with few strong motion data, while the analytical and hybrid techniques utilize data either directly or at least for calibration purposes to constrain free parameters.

In many areas of the world, however, there exists active tectonism and therefore considerable seismic exposure but the strong motion data base is extremely sparse. In these cases, an empirical relation based upon non-region specific data may simply be adopted. If time histories are required, conventional scaling techniques are employed generally using WUS

acceleration data. The justification primarily relies upon arguments considering similar tectonic environments, crustal structure, style of faulting, depth of events, observed attentuation of shaking intensity and other less tangible aspects generally referred to as engineering judgement. While this methodology is an accepted practice by necessity, an approach is needed which does not rely upon strong motion data for calibration but rather only for confirmation.

2.0 APPROACH

Another approach, which utilizes simple earthquake source theory and wave propagation physics, has recently demonstrated great promise in circumstances such as these (Boore, 1983; Atkinson, 1984, McGuire et al., 1984). The basic advantage lies in using weak motion indirectly to predict strong motion. The weak motion is due to small magnitude (generally less than $M_W = 5$) local or regional events. These data, from both analogue and digital recordings, are used to estimate region specific source and wave propagation parameters. Those parameters are then input to the source and propagation models which predict the motion due to events at distances and from source sizes for which no data exist. This approach employs random vibration theory (RVT) applied to a Brune source spectrum (Brune; 1970, 1971) to characterize strong ground motion. While this approach is not perfect, and some problems remain, we believe that, based upon its recent success (Boore, 1983; Atkinson, 1984, McGuire et al., 1984) and our preliminary results, it will prove to be quite useful.

2.1 Model

The formalism employed to develop an attenuation relation with little or no strong motion data is based upon a simple theoretical model of the earthquake process and wave propagation physics. The theoretical basis was developed and calibrated with observed data by Hanks and McGuire (Hanks, 1979; McGuire and Hanks, 1980; Hanks and McGuire, 1981). They used the Brune (1970, 1971) spectrum to model root mean square (RMS) acceleration as a function of magnitude and distance for stiff (rock) sites. To model peak values, they utilized results from random vibration theory to relate the RMS predictions to maximum values. Boore (1983) has extended the range of applications to include predictions of peak horizontal velocities, Wood-Anderson seismographic response, and response spectra. Boore has also used this approach to generate synthetic acceleration time histories by employing random sequences whose spectra match the predicted Brune spectrum. The method leads to results which reproduce the empirical dependences of peak acceleration, peak velocity,

reproduce the empirical dependences of peak acceleration, peak velocity, and pseudovelocity response spectral amplitudes on moment magnitude at close distances. McGuire et al. (1984) further confirmed the results of the RVT technique by demonstrating the close agreement between observed and predicted response spectral values. They also showed good agreement between the calculated Brune spectrum and the acceleration spectral density of empirical data for several discrete frequencies. In order to extend this approach to large distances, the model was modified to incorporate surface wave effects (Atkinson, 1984). At distances greater than about two crustal thickness (Herrmann, 1985), surface waves rather than shear waves, will carry the peak ground motion.

The technique developed in this study employs aspects of the above developments to predict peak values (acceleration and velocity) and response spectra. However it differs significantly from other techniques in the manner in which time histories are generated. These time histories may be regarded as semi-empirical in that they use the Brune spectrum as a modulus but an observed phase to generate the complex spectrum. The advantage of this technique is that the non-stationarity, randomness, and change in frequency with time is incorporated in a natural way. Intergrations to velocity and displacement are then also more realistic. The basic assumption with this technique is that the region-specific source and wave propagation parameters are reflected primarily in the spectral modulus. The phase spectrum accounts for the multipath effects and surface wave contributions.

Since the RVT technique, employing a Brune spectrum, has demonstrated success in modeling both Western and Eastern United States data, the RVT peak values (acceleration and velocity) are used to scale the time domain simulations. This is necessary since we are generally combining a modulus and a phase which are somewhat incompatible. This arises because the phase is from a time history with mixed phase properties while the Brune spectrum is smooth (Pilant and Knopoff, 1970).

In order to preserve the magnitude dependency of strong motion duration characteristics (Dobry et al., 1978) it is necessary to use a phase from a record of approximately the same magnitude and distance as the design event. This arises because the phase spectrum determines how the energy is distributed in time. The magnitude similarity is about ± one half unit of magnitude. The distance requirement on the phase is less restrictive. Generally, we have found phases extracted from records within 20 to 25 km can be used for simulations from 10 to 30 km. Phases from records at 40 to 50 km are used for distances greater than 30 km.

In cases where a time history is required when a target response spectrum is specified, an initial Brune spectrum is generated based upon magnitude, stress drop, and distance in addition to the region specific wave propagation parameters. The Brune spectrum is then scaled by taking ratios of either, the RVT response spectra or a time domain response spectrum calculation, to the target response spectrum. The time domain response spectrum is calculated from the synthesized time history. The peak acceleration of the resultant time history is generally then scaled to the design value (which must be consistent with the target response spectrum).

3.0 OBJECTIVE

The original objective of this work was to develop a technique to generate a realistic time history whose response spectrum is compatible with a specified response spectrum. The plan was to use an observed time history and scale the modulus of its Fourier spectral density by the ratio of the observed response spectra to the target. The original phase would then be added to produce the desired time history. The process would be iterated until the response spectra of the scaled time history was close to the target response spectrum. However, in developing the code it was decided to abandon the observed modulus since the RVT technique had recently demonstrated such good results by employing the simple Brune spectrum. The most convincing evidence came from McGuire et al., (1984). They showed the effectiveness of the Brune spectra in predicting Fourier spectral density and response spectral values at close distances for several frequencies. By using a combined approach, that is a Brune modulus with an observed phase, it is possible to also incorporate all the predictive power of the RVT methodology. That is, in one code, the ability to predict peak acceleration, peak velocity, and response spectra in addition to generate realistic acceleration, velocity, and displacement time histories has been incorporated. This can be done for magnitudes from about 4 to 7 1/2 and from distances from 10 km to over 100 km. In addition a target response spectrum may be input to the code and an acceleration time history can then be generated whose response spectrum closely matches the target response spectrum.

4.0 RESULTS

Since the code, as it is presently configured, operates in two basic modes depending upon whether or not a target response spectrum has been specified, the results section will be divided accordingly. The first section will address the predictive capability in terms of peak values for WUS and EUS tectonic environments. The time history synthesis will also be demonstrated. The second section will present the scaling results when an input target response spectrum is specified.

4.1 Prediction and Synthesis Capability

In order to demonstrate the predictive characteristics of the code, results for both magnitude and distance scaling will be presented. Magnitude scaling will include comparisons of peak acceleration and peak velocity at close distances with empirical relations for WUS and EUS tectonic environments. Distance scaling will involve predicted peak acceleration vs distance for a single magnitude compared with empirical data. Source and wave propagation parameters used for WUS and EUS predictions are shown in Table 1.

Figure 1 demonstrates the magnitude scaling for close distances (R<15 km) compared to three other attenuation relations: Joyner-Boore (1982) at 50% level, Seed and Schnable (1980), and Donovan (1973). The bars at magnitudes 5 and 7 1/2 represent the scatter in the data base used by Joyner and Boore (1981). The lower magnitude variances are for the Oroville aftershocks combining rock and soil sites (Shakal and Berneuter, 1980). All data are for distances of a few km to 15 km. Both the Joyner-Boore (1982) and Seed and Schnable (1980) curves are plotted for magnitude ranges over which the authors indicated the relations are valid. These relations are based upon WUS data. The Donovan (1973) curve, which is based upon world wide data, is plotted for the entire range since no discussion is given outlining the range of its validity. It should also be pointed out that there are differences in definitions of distance which are significant at these close ranges. The calculated relation is based

upon a hypocentral distance of 10 km while the Joyner-Boore (1982) curve uses the closet distance to the surface projection of the fault. Seed-Schnable (1980) and Donovan (1973) employ a "closest" distance. These differences in definition can easily result in differences of 0.2 to 0.3 log units at these close distances (Hanks and McGuire, 1981). The RVT predictions, which include the near site amplification factors (Boore, 1985), appears somewhat high but is generally within the 85% Joyner Boore (1982) curve (0.27 log units higher than the curve shown in figure 1). Also, for the higher magnitudes, 10 km is well within the source dimension which violates the far-field assumption in the Brune (1970, 1971) theory. With these considerations, we are favorably impressed with the results.

Peak particle velocities vs moment magnitude are plotted in Figure 2 for WUS parameters. Also shown is the empirical curve of Joyner and Boore (1982). Here the agreement between the calculated values and the empirical relation is quite good over the entire range in magnitudes.

Distance scaling of peak acceleration is shown in Figure 3 for a moment magnitude of 7 at a focal depth of 10 km. The data are from the 1979 Imperial Valley event (M_S = 6.8; Idriss, 1983). The median and $\pm$ 1 σ curves are from a fit to the data (Idriss, 1983). The calculated values (open symbols) generally fall within the data indicating a realistic distance scaling.

Eastern United States scaling is shown in Figure 4. In this case, the near site amplification factors are not employed since the velocity gradients in the top 1 km or so are much less in the EUS. The plot compares predicted EUS peak acceleration values vs magnitude (m_b) to several other relations. The figure was taken from Atkinson (1984). The predicted values (open symbols) are generally within the range of the other relations. This indicates that the model agrees with other predictions of magnitude scaling at close distances for the EUS tectonic environment. Figure 5 shows the same results for peak velocity. Here a much wider range is shown by the relations but again the model predictions

are generally consistent with those obtained using other relations.

Distance scaling for the peak acceleration in the EUS is shown in Figure 6. The data are from the Miramichi, St. Lawrence, New Hampshire areas and are scaled to $m_b = 5.0$ (see figure). The line is from Atkinson (1984) and represents her RVT results for Eastern Canada. The model predictions (open symbols) are for a source depth of 4 km and lie well within the scatter of the data. The figure was taken from Atkinson (1984).

An important consideration in the analysis of degrading systems such as liquifiable soil deposits and saturated earth embankments is the number of cycles of loading. This is related to the time history through measures of duration. In order to assure that the synthesized time histories reflect an appropriate increased duration with magnitude, the significant durations were monitored for moment magnitude 4 to 7 and at hypocentral ranges of 10 and 50 km. The results are shown in Figure 7 along with the empirical curve of Dobry et al. (1978) for the 5% to 95%, Arias intensity at close distances. The Dobry et al. curve is shown over the range of their data and the synthetic results agree well for magnitudes 6 to 7. The agreements degrades for lower magnitudes but the scatter in this type of data is large. In general, the synthetic results shown the expected trend with magnitude and distance.

The corner period is also shown vs moment magnitude in Figure 7. This relation (Table 1) is nearly within $\pm 2\sigma$ and demonstrates that the inverse corner frequency (source duration) can be a good measure of the lower bound estimates of strong ground motion duration at close distances.

The time domain synthesis is shown in Figure Set 8 for both Western and Eastern United States scaling (Table 1). Acceleration, velocity, and displacement time histories are shown for a magnitude 7 (M_W for WUS and m_b for EUS) event at 10 km. Peak time domain accelerations and velocities are scaled to the corresponding RVT peaks while the displacements are integrated from the scaled accelerations. For many applications is site response analysis, it is desirable to produce time histories and response

spectra at shallow depths. This would correspond to embedded structures with foundations within a soft or stiff site. In order to accommodate this feature, the code includes a single layer site response transfer function (Section 6). While most sites have material properties which vary with depth, the overall effects of burial may be represented by a single layer with correctly averaged properties. The results for a receiver at a depth of 20 m within a 40 m thick soil sites (Table 3) are shown in Figure Set 8 for WUS parameters. The respective response spectra are also shown in Figure Set 8. The depth dependent spectral node at around 4 Hz is clearly visisble in the at-depth response spectrum.

An example of the RVT response spectra is shown in Figure Set 9. The upper solid line in plot (A) is the pseudo relative velocity response spectrum for a moment magnitude 6 event at a distance of 10 km calculated using the RVT formulation. The scaling is for the WUS (Table 1) and the open circles were taken from Boore (1983) and represent regression fits to WUS data. The agreement is reasonably good and well within the variability of the data. We should also recall that the RVT calculations represent expected values (Udwadia and Trifunac, 1974). The 5 to 95% confidence limits depend upon N, number of peaks) but in general the range is about 50% above and below the expected value (Udwadia and Trifunac, 1974). The kinks at the long period end of the RVT response spectrum are due to N changing with frequency. At long periods N is small so a change in one unit has a substantial effect on the peak to RMS ratio.

4.2 Response Spectral Scaling Capability

In order to demonstrate the response spectral scaling capability for the code, a design spectrum from a previous Woodward-Clyde project has been utilized in order to compare results of the present formulation with current practice.

The response spectral scaling approach taken in this code employs both RVT and time domain response spectra calculations. Since RVT response spectra calculations are less costly than time domain evaluations, the first

iterations (1 or 2) are done with this technique. This also provides for a more stable convergence since, during the first few iterations, the Brune spectra are perturbed the greatest, therefore using extremely smooth RVT response spectra results in non-oscillatory scaling factors. Since the RVT response spectra are expected values, the response spectra calculated from the synthesized time history may depart from these estimates by as much as ± 50%. This variability is due to the use of an observed phase spectrum and reflects path and site effects. To correct for this, the final iterations (1 or 2) are done employing response spectrums calculated from the synthesized time histories. Direct integration of the oscillator equation is performed (Nigam and Jennings, 1968). For oscillator periods less than 10 times the sample interval, the acceleration time histories are linearly interpolated. This was done to provide more accurate high frequency response calculations.

Figure Set 9 shows the target or design response spectrum and the scaling results. The design event is taken to be a WUS earthquake with a moment magnitude of 6 at a distance of 20 km. The peak acceleration is specified at 0.125 g. The high frequency limit (50 Hz) of the target PRSV gives a peak acceleration of 0.123 g so the design peak acceleration and the high frequency limit of the PSRV are consistent. Plot (A) shows the design PSRV and the initial RVT response spectrum. Also shown are the results after the first two iterations employing RVT spectrum calculations and the final two iterations using the time domain response spectra calculations. The convergence is remarkably fast and the fit is good. Plot (B) shows the Fourier spectral density after each set of two iterations. The oscillations introduced into the Fourier spectra when using time domain response spectra calculations for scaling are readily apparent. It is interesting to note that these oscillations are due to the randomness of the observed phase since the RVT scaled Brune spectra are quite smooth (dotted line in Plot (B)). Thus the randomness in the observed phase is indirectly coupled into modulus through the scaling factors. The Fourier spectra then takes on a more realistic appearance. In order to provide a meaningful integration to velocity and displacement, the final Fourier spectra are band-pass filtered with five-pole causal Butterworth filters. In this case the high-pass corner was 0.25 Hz and

the low-pass corner is 23 Hz. The results of the filtering on the response spectra are shown in plot (C). The effects of the high-pass filter propagate up to about 0.7 Hz.

The acceleration, velocity, and displacement time histories are shown in plots (d) of Figure Set 9. The time histories appear very realistic with little wrap-around problems. The acceleration, with a peak of 0.116 g, displays typical non-stationarity and change in frequency with time. The integrations to velocity and displacement display reasonable values and shapes.

In order to produce the design peak acceleration of 0.125 g, the acceleration time history was normalized to this value after the last iteration. The resulting response spectra and time history are shown in Figure Set 10. Plot (a) shows the response spectra which is now slightly above the target response spectra. This arises because the normalization process to scale the peak acceleration to 0.125 g scales the entire time history resulting in a perturbed response spectrum throughout the entire bandwidth of oscillator frequencies. A more proper manner of accomplishing this would be to perturb the Fourier spectra in the frequency range which controls the time domain peak. From Figure Set 9, plot (B), this can be seen to occur around 2 Hz. Nevertheless, we consider the fit quite acceptable.

Figure Set 11 shows the results, for the same target response spectra and peak acceleration employing another scaling technique. The approach used here was to piece together elements from several time histories until the resulting response spectra approximated the design response spectra. At that point, spectrum raising and lowering techniques were applied (Tsai, 1972) to provide the match shown in the first plot. The fit is quite good but the time histories appear somewhat unrealistic. The velocities and displacements are naturally less satisfying than the acceleration and may represent little more than the results of processing.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In general, we are favorably impressed with the results of the code. The use of RVT methodology in the prediction aspect for peak values and response spectra appears to yield appropriate results with both WUS and EUS magnitude and distance scaling. The simple and straigthforward approach to time domain synthesis produces realistic earthquake acceleration, velocity, and displacement records. The time histories display characteristic non-stationarity and change in frequency content with time without resorting to envelope functions or other devices. The acceleration records additionally show expected increases in duration with magnitude and distance.

The response spectral scaling methodology resulted in very rapid convergence (2-4 iterations) to the target design spectrum. The resulting spectrum compatible time histories again displayed very realistic properties, particularly when compared to results employing a conventional technique. Another advantage of the RASCAL code in response spectral scaling applications is the ease of use and cost effectiveness. Once a design spectrum has been generated, one run of the code may be all that is required versus about 2 man weeks for conventional techniques.

6.0 MATHEMATICAL DEVELOPMENT

Following McGuire and Hanks (1980) and Boore (1983) the modulus of the acceleration spectral density for a Brune (1970, 1971) pulse may be written as

$$\hat{a}(f) = \frac{(0.78)}{4\pi\rho\beta^3} \quad \frac{e^{-\frac{\pi f R}{\beta Q(f)}}}{R} \quad \frac{(2\pi f)^2 M_o}{1 + \left(\frac{f}{f_c}\right)^2} \qquad (5.1)$$

where 0.78 accounts for the free surface effect (2), participation of energy into two horizontal components (2-1/2), and an average radiation pattern (0.55).

The source and wave propagation parameters are:

M_o seismic moment

f_c corner frequency; given by (Boore, 1983) (5.2)

$$f_c = 4.9 \times 10^6 \beta \left(\Delta\sigma / M_o\right)^{\frac{1}{3}}$$

$\Delta\sigma$ stress drop

$Q(f)$ half space attenuation coefficient; given by

$$Q(f) = Q_o \left(f / f_o\right)^{\alpha} \qquad \text{(Herrmann, 1980)} \quad (5.3)$$

ρ half space density

β half space shear wave velocity

R hypocentral range

Tectonic specific scaling is achieved through the above region dependent parameters. Magnitude dependence may be incorporated through specifying a moment-magnitude relation. For WUS the moment magnitude is generally used,

$$\log M_0 = 1.5\ M_W + 16.1 \qquad \text{(Hanks and Kanamori, 1979)} \qquad (5.4)$$

while for these simulations the following EUS m_b relation was used

$$\log M_0 = 1.75\ m_b + 14.12 \qquad \text{(EPRI, 1985)} \qquad (5.5)$$

Random vibration theory (RVT is implemented by specifying the relationship between peak values (acceleration, velocity, oscillator response for response spectra) and root mean square (RMS) values. RMS is calculated in the frequency domain through Parseval's relation (Aki and Richards, 1981)

$$a_{RMS}^2 = \frac{2}{T} \int_0^\infty \tilde{a}^2(f)\, df \qquad (5.6)$$

where T is a measure of the duration of the acceleration time history (Vanmarke and Lai, 1980).

The relationship between expected value of the peak ($E(a_p)$) and the RMS value (a_{RMS}) is based upon the work of Cartwright and Longuet-Higgens (1956) and Udwadia and Trifunac (1974). The following method is taken from Boore (1983, 1985) who applied it to estimating peak acceleration, peak velocity, response spectral ordinates, Wood-Anderson response, and to evaluate spectral scaling relations.

The following development is in terms of predicting peak acceleration but the application to peak velocity is identical. The application to prediction of response spectra is also demonstrated.
The expected value of the peak acceleration is given by

$$E(a_p) = a_{RMS} \sqrt{\frac{\pi}{2}} \sum_{\ell=1}^{N} (-1)^{\ell+1} \frac{C_\ell^N}{\sqrt{\ell}} \zeta^\ell \tag{5.7}$$

where a_{RMS} is calculated through Equation (5.6) utilizing the Brune spectra, $C^N{}_1$ are the binominal coefficients (N!|1! (N-1)!) and ζ is a measure of the bandwidth:

$$\zeta = m_2 / (m_0 m_4)^{\frac{1}{2}} \tag{5.8}$$

The m_k are moments of the energy density spectrum given by

$$m_k = 2 \int_0^\infty (2\pi f)^k \hat{a}^2(f)\, df \tag{5.9}$$

The limit of the sum (N) is defined as the number of extrema in the acceleration time history of duration T which is taken as f_c^{-1} (Hanks and McGuire, 1981). An estimate of this number is given by

$$N = 2 \tilde{f} T \tag{5.10}$$

where $\tilde{f}$ is the predominant frequency

$$\tilde{f} = \frac{1}{2\pi} \left(\frac{m_4}{m_2} \right)^{\frac{1}{2}} \tag{5.11}$$

The minimum value of N is set at 2 (Boore, 1983) while if N is greater than 20 an asymptotic expression is used for $E(a_p)$;

$$E(a_p) = a_{RMS} \left\{ (2 \ln N)^{\frac{1}{2}} + \frac{\gamma}{(2 \ln N)^{\frac{1}{2}}} \right\}$$

(Clough and Penzine, 1975) (5.12)

where N, still defined by Equation (5.10), is the number of zero crossings in the time T. In this case the predominant frequency $(\tilde{f})$ is defined by

$$\tilde{f} = \frac{1}{2\pi} \left(\frac{m_2}{m_0} \right)^{\frac{1}{2}} \tag{5.12}$$

The a_{RMS} is given by

$$a_{RMS} = (m_0 / T)^{\frac{1}{2}} \tag{5.13}$$

from Equations (5.6) and (5.9).

In order to employ the RVT technique to estimate the response spectrum, the oscillator transfer function is incorporated into Equation (5.9). The peak value from Equation (5.7) or Equation (5.12) is then the response spectral ordinate for a particular oscillator damping and resonant frequency. To see this we may write out the inhomogenous oscillator Equation

$$\ddot{X} + \omega_n \zeta \dot{X} + \omega_n^2 X = -a(t) \tag{5.14}$$

where X is the oscillator displacement, ζ the damping, and a(t) the acceleration time history. Taking Fourier transforms and multiplying by f_n^2 ($f_n = \omega_n / 2\pi$) the modulus of Equation (5.14) may be written as

$$f_n^2 X = \frac{f_n^2}{\left\{(f_n^2 - f^2)^2 + (2\zeta f f_n)^2\right\}^{\frac{1}{2}}} \left(-\hat{a}(f)\right) \tag{5.15}$$

where $f_n^2 x$ is the pseudo acceleration (Hudson, 1979). The psuedo acceleration transfer function is then

$$H(f_n, \zeta, f) = \frac{f_n^2}{\left\{(f_n^2 - f^2)^2 + (2\zeta f f_n)^2\right\}^{\frac{1}{2}}} \tag{5.16}$$

and when H^2 (f_n, ζ , f) is included in the intergrand of Equation (5.9), the resultant RVT peak is the pseudo acceleration spectral ordinate for a given ζ and f_n. The present code uses Simpson's rule to perform the integrations.

For response spectra calculations, a modification is needed to the duration T. This arises because for short duration time histories, the longer period oscillators do not have sufficient time to build up their RMS response. Boore and Joyner (1984) have an empirical correction factor which employs an equivalent duration T_{RMS} which is greater than T and is given by

$$T_{RMS} = T + D_0 \frac{\gamma^3}{\gamma^3 + 1/3} \tag{5.17}$$

where

$$D_0 = (2\pi \zeta f_n)^{-1}, \quad \gamma = T / D_0 \tag{5.18}$$

This extended duration is then used in Equation (5.10) to estimate N and in Equation (5.13) for the RMS calculation.

In order to accommodate surface wave effects at large distances (R>100 km) the code has an option to incorporate $R^{-1/2}$ geometrical attenuation rather than the body wave R^{-1} attenuation beyond 100 km.

The dominance of higher mode surface waves beyond about two crustal thicknesses ($\gtrsim$100 km) also cause the ground motion duration to be longer

than the source duration ($T = f_c^{-1}$). A correction factor, based upon empirical and synthetic records, has been developed (Herrmann, 1985) which shows the duration proportional to distance

$$T = f_c^{-1} + 0.05R\ (km) \tag{5.19}$$

Both of these distance correction should be used for distances greater than 100 km.

In order to curtail the Brune spectrum at the high frequencies, a high cut filter that accounts for the observation that acceleration spectra often show a sharp decrease with increasing frequency, above some cut-off frequency (f_{max}) is added to Equation (5.1). It represents a near site (Hanks, 1982) or source effect (Papagerogiou and Aki, 1983) which curtails the high frequency energy. Its effect is generally modeled as a low pass fourth order Butterworth filter (Boore, 1983) with a modulus given by

$$\sqrt{\frac{1}{1 + \left(\frac{f}{f_{max}}\right)^8}}$$

An alternate model for this high frequency attenuation is of exponential form.

$$\text{Exp}\ (-\pi f k) \qquad \text{(Anderson and Hough, 1984),}$$

where kappa (k) is a region specific parameter. Incorporation of this filter into the RVT source model has not demonstrated as optimum a fit to

observed peak acceleration data as the f_{max} type filter (Luco, 1985; Boore, 1986).

In many ground response analyses, there is an interest in ground motion at embedment depth rather than at the free surface. In order to accommodate this, the transfer function for a single layer, assuming normal incidence, of thickness H, has been incorporated into the code. All calculations; peak values, time histories, and response spectra, are then evaluated at a depth h (may be zero) within the layer. The layer is defined by a shear velocity, density, and damping and is assumed to overlie an elastic half-space. While this is not exact since the half-space Q is not infinite (a WUS Q of 300 is probably a minimum value) the error should not exceed a few percent.

The transfer function for the layer is given by

$$\frac{\cos k^* h}{\left\{ \cos^2 k^* H + \left(\frac{\rho_1 \beta_1}{\rho_2 \beta_2} \sin k^* H \right)^2 \right\}^{\frac{1}{2}}} \qquad (5.20)$$

where

$$k^* = \frac{\omega}{\beta} \left(1 + i \zeta \right) \qquad (5.21)$$

β = layer shear wave velocity

ζ = damping of layer

H = layer thickness

h = receiver depth ($\leq$ H)

and subscripts 1 and 2 refer to the layer and half-space respectively. For non-zero h, only the modulus of H_L is used since the RVT technique employs the power spectrum to calculate the RMS values (Equation (5.6)). For time domain calculations, this may introduce some signal distortion but generally site thicknesses are less than the wavelengths of predominant energy so the effects should be minimal. Several tests have shown this to be the case.

An additional caution in using the site response in the RVT calculations arises regarding the duration calculations (Herrmann, 1985). If a very soft site is specified, such that considerable energy can be trapped due to reflected waves, the effective duration is increased much like the higher mode surface waves at large distances. This effect however, is not compensated for in the RVT theory so the peak values may be biased. The RVT approach then should not be employed to model expected peak or response spectral values for application's where site response dominates the motion.

Another correction factor, designed to explicitly account for wave amplification due to decreasing seismic velocities near the earth's surface, has been incorporated. Boore (1985) has calculated typical WUS frequency dependent factors based upon an average velocity change over one quarter wavelength (Joyner and Fumal, 1984). The equation, based upon energy conservation is given by

$$A = \sqrt{\frac{\beta_o \rho_o}{\beta_R \rho_R}} \tag{5.22}$$

where the subscripts o and R refer to average crustal properties and near the receiver respectively. The WUS factors are given in Table 2 for several frequencies (Boore, 1985). Values for intermediate frequencies are linearly interpolated while values for frequencies which are outside the specified range are merely extended.

7.0 USER MANUAL

The code has been given the name RASCAL which stands for Response Spectra and Acceleration Scaling. We have referred to it by many less eloquent names during its development but RASCAL seems to capture the essential elements. No plotting routines are incorporated since these are highly user and machine dependent. Pertinent files are created and the user is free to plot sizes and the scales of choice.

Included with the code is a library of basis time histories which are used to generate the phase spectra. The bases are shown in Figure set 12 and each plot title describes the time history. The distance and magnitude selection criterion are shown in Table 4. The basis library time histories are coded in local magnitude (M_L) and in hypocentral range (R). The code is presently compiled in FORTRAN F77 on a PRIME 750 and an AT compatible microcomputer. It was designed to be as machine independent as possible to allow for greatest flexibility.

7.1 Prediction Methodology

To predict peak values and RVT response spectra, relevant parameters must be specified along with the proper KEYS. This is explained in detail in the User's Guide (7.4).

7.2 Synthesis Methodology

Once the source and wave propagation parameters are specifed, selection of the proper KEY (see User's Guide) will produce a time history. The basis time history, from which the phase is extracted, may be user supplied (external) or automatically selected from the library (internal). Table 4 lists the library contents along with the magnitude and distance selection criterion. If a time history is supplied, the total number of points must not exceed 2048. Also, since both an RVT response spectrum and one based

upon a time domain integration are produced, the total length of the time history must exceed 10 seconds. This arises because the longest period oscillator in the time domain response spectrum calculation is 10 seconds. Zeros may be appended prior to inputting the external basis to fill out the array to 10 seconds. At the high frequency end, the highest oscillator frequency is set to 0.7 f_n (f_n = Nyquest frequency) or 34 Hz, whichever is smaller.

The actual oscillator frequencies are included in a data statement. They consist of the NRC specified values in additional to selected intermediate values and represent a standard WCC (Woodward-Clyde Consultants) format of 143 values (see User's Guide).

The peak time domain values of the acceleration or velocity are normalized to either the respective RVT predicted peaks or to input values (see User's Guide). When integrating to velocity or displacement, filtering should be performed. The filter supplied is a causal Butterworth which can be applied twice to provide band-pass capability. Guidelines for corner periods for the high-pass flter vary but we generally assume a sufficient signal to noise ratio out to the source corner period (f_c^{-1}). We therefore put the filter corner at a slightly longer period and use a fall-off of 30 db/octave (5 pole).

7.3 Response Spectral Scaling Methodology

Either pseudo acceleration or psuedo velocity may be entered as the target response spectrum. The frequency range should be from 0.1 Hz to 34 Hz with enough points to define the curve (max = 143). Values higher than 34 Hz may be input, but only values between 0.1 Hz and 34 Hz are employed. The low frequency limit (0.1 Hz) is fixed.

The first few (user specified) iterations are performed using the RVT response spectrum to scale the Brune spectrum. The final few (user specified) iterations use a standard time domain integration algorithm to calculate the response spectrum from the synthesized acceleration time

history. This response spectrum is then used to scale the Brune modulus. The final acceleration time history may be either normalized to an input value or left unscaled.

7.4 User's Guide

```
C
C ---- PROGRAM  R A S C A L
C
C       PROGRAM RASCAL (RESPONSE SPECTRUM AND ACCELEROGRAM SCALING)
C       COMPUTES BRUNE FOURIER AMPLITUDE BASED ON THE METHOD SUGGESTED
C       BY J. N. BRUNE (BSSA, VOL. 75, SEPTEMBER 1970) AND COMPUTES PEAK
C       ACCELERATION, PEAK VELOCITY, RESPONSE SPECTRAL ACCELERATION AND
C       RESPONSE SPECTRAL VELOCITY BASED ON THE METHOD SUGGESTED BY D. M.
C       BOORE (BSSA, VOL. 73, DECEMBER 1983) BY USING RANDOM VIBRATION
C       THEORY (RVT) TECHNIQUES.
C
C       THE PROGRAM ALSO GENERATES SYNTHETIC TIME HISTORY (ACCELERATION,
C       VELOCITY OR DISPLACEMENT) BY COMPUTING THE FFT AND EXTRACTING THE
C       PHASE OF AN INPUT ACCELEROGRAM (INTERNAL OR EXTRENAL BASE) AND
C       COMBINES THE COMPUTED BRUNE FOURIER AMPLITUDE TO GENERATE THE
C       OUTPUT TIME HISTORIES.
C
C       FOR RESPONSE SPECTRUM AND ACCELEROGRAM SCALING, THE PROGRAM SCALES
C       THE COMPUTED RVT RESPONSE SPECTRUM WITH THE INPUT DESIGN (TARGET)
C       RESPONSE SPECTRUM. THIS PROCESS REPEATS FOR A SPECIFIIED NUMBER OF
C       TIMES AND THE SPECTRAL MATCHING SHOULD CONVERGE AFTER 2 TO 3
C       ITERATIONS. DURING THIS ITERATIVE SPECTRAL SCALING OF THE RVT
C       RESPONSE SPECTRUM, THE COMPUTED BRUNE FOURIER AMPLITUDE IS ALSO
C       SCALED. THE PROGRAM THEN COMBINES THIS SCALED BRUNE FOURIER
C       AMPLITUDE WITH THE PHASE OF THE INPUT ACCELEROGRAM AND COMPUTES AN
C       OUTPUT ACCELEROGRAM. THIS OUTPUT ACCELEROGRAM IS THEN USED AS AN
C       INPUT ACCELEROGRAM TO COMPUTE A SINGLE-DEGREE-OF-FREEDOM (SDF)
C       RESPONSE SPECTRUM. AGAIN, THE PROGRAM SCALES THE COMPUTED SDF
C       RESPONSE SPECTRUM WITH THE INPUT (TARGET) RESPONSE SPECTRUM,
C       SCALES THE BRUNE FOURIER AMPLITUDE SIMULTANEOUSLY, AND COMPUTES AN
C       OUTPUT ACCELEROGRAM. THIS PROCESS ALSO REPEATS FOR ANOTHER
C       SPECIFIED NUMBER OF TIMES. FINALLY, THE PROGRAM NORMALIZES OR
C       FILTERS THE OUTPUT ACCELROGRAM AND COMPUTES SDF RESPONSE SPECTRUM
C       BASED ON THIS CONDITIONED OUTPUT ACCELEROGRAM.
C
C       THIS PROGRAM HAS THE CAPABILITY OF COMPUTING THE HALF-SPACE (ROCK
C       OUTCROP) OR SITE (SINGLE-LAYERED SOIL) RESPONSE AND OF GENERATING
C       OUTPUT VELOCITY OR DISPLACEMENT TIME HISTORY AS WELL.
C
C
C --- U S E R ' S   G U I D E
C
C --- BASIC PARAMETERS :
C
C       1.  TITLE : FORMAT(A80)
C           TITLE IS THE TITLE OF THE RUN.
C
C       2.  OFILE : FOMAT(A80)
C           OFILE IS THE OUTPUT FILE NAME OF THE RUN.
C                 OUTPUT FILES OF SPECTRAL VALUES, ACCELERATION, VELOCITY,
C                 AND DISPLACEMENT TIME HISTORIES ARE AUTOMATICALLY CREATED
C                 SEPARATELY UNDER THIS OFILE NAME WITH SUFFIXES OF SP, A,
C                 V AND D RESPECTIVELY, AND OF NUMBER OF ITERATIONS AT THE
C                 END OF EACH FILE.
C
C       3.  SDROP, DENS, D, H, SV : FORMAT(FREE)
```

```
C
C         SDROP IS THE STRESS DROP (BARS).
C         DENS IS THE MEDIUM DENSITY (GM/CC).
C         D IS THE EPICENTRAL DISTANCE (KM).
C         H IS THE SOURCE DEPTH (KM).
C         SV IS THE SHEAR WAVE VELOCITY OF THE HALF-SPACE (KM/SEC).
C
C     4.  Q, FQ, ALPHA, MW : FORMAT(FREE)
C         Q IS THE FREQUENCY DEPENDENT QUALITY FACTOR OF THE HALF-SPACE
C           FOR Q FILTER, WHERE Q(F) = Q * ( F / FQ ) ** ALPHA.
C         FQ IS THE CONTROL FREQUENCY FOR THE Q QUALITY FACTOR (HERTZ).
C         ALPHA IS THE EXPONENTIAL CONSTANT FOR THE Q OPERATOR.
C         MW IS THE MOMENT MAGNITUDE.
C
C     5.  DAMP, FMAX, N, CAP : FORMAT(FREE)
C         DAMP IS THE SPECTRAL DAMPING (PERCENT).
C              (MUST BE BETWEEN 1 TO 10 %).
C         FMAX IS THE BUTTERWORTH CORNER FREQUENCY (HERTZ).
C              (IF FMAX = 0, NO FILTERING IS PERFORMED).
C         N IS THE FMAX ORDER NUMBER.
C           (IF N = 0, NO FILTERING IS PERFORMED).
C         CAP IS THE CONSTANT, KAPPA FOR NEAR-SITE EXPONENTIAL
C             FILTERING.
C              (IF CAP = 0.0, NO FILTERING IS PERFORMED).
C
C --- FUNCTIONAL KEYS :
C
C     6.  KEY1, KEY2, KEY3, KEY4, KEY5, KEY6 : FORMAT(FREE)
C         KEY1 IS THE KEY FOR COMPUTING SPECIFIED RESPONSE.
C              IF KEY1 = 0 : COMPUTES HALF-SPACE RESPONSE.
C              IF KEY1 = 1 : COMPUTES SITE RESPONSE.
C         KEY2 IS THE KEY FOR APPLYING NEAR-SITE AMPLIFICATION FACTOR
C              AS A FUNCTION OF FREQUENCY.
C              IF KEY2 = 0 : NO AMPLIFICATION FACTORS ARE APPLIED.
C              IF KEY2 = 1 : AMPLIFICATION FACTORS ARE APPLIED.
C         KEY3 IS THE KEY FOR CHANGING GEOMETRICAL ATTENUATION FOR
C              R > 100 KM.
C              IF KEY3 = 0 : BODY WAVE ( 1 / R ) IS RETAINED FOR
C                            FOR R > 100 KM.
C              IF KEY3 = 1 : ATTENUATION FOR R > 100 KM. IS APPLIED.
C                            ( FOR R < 100 KM., ATTENUATION = 1 / R ).
C                            ( FOR R > 100 KM., ATTENUATION = 1 / 100 *
C                              SQRT( 100 / R ) ).
C         KEY4 IS THE KEY FOR INCREASING EFFECTIVE SOURCE DURATION DUE
C              TO SURFACE WAVE CONTRIBUTION.
C              IF KEY4 = 0 : DURATION = 1 / FC .
C              IF KEY4 = 1 : DURATION = 1 / FC + 0.05 * R .
C                 (FROM R. B. HERRMANN, BSSA, VOL. 75, OCTOBER 1985).
C         KEY5 IS THE KEY FOR GENERATING ARTIFICIAL ACCELERATION TIME
C              HISTORY.
C              IF KEY5 = 0 : NO ARTIFICIAL ACCELERATION TIME HISTORY IS
C                            GENERATED. JUST BASIC RESPONSE IS COMPUTED.
C                            IN THIS CASE, NO NUMBER OF ITERATIONS AND
C                            DESIGN (TARGET) RESPONSE SPECTRUM ARE
C                            REQUIRED. SET KEY6 = 0 !!!
C              IF KEY5 > 1 : ARTIFICIAL ACCELERATION TIME HISTORY IS
C                            GENERATED USING PHASES OF THE BUILT-IN
```

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C

C                              ACCELERATION TIME HISTORY.
C                IF KEY5 < 1 : ARTIFICIAL ACCELERATION TIME HISTORY IS
C                              GENERATED USING PHASES OF THE INPUT
C                              ACCELERATION TIME HISTORY.
C           KEY6 IS THE KEY FOR WRITING OUTPUT TIME HISTORIES, OFILE.
C                IF KEY6 = 0 : ONLY OUTPUT ACCELERATION TIME HISTORY OF THE
C                              LAST ITERATION IS WRITTEN IN OFILE.A, OR NO
C                              OUTPUT TIME HISTORIES ARE WRITTEN AT ALL IF
C                              KEY5 = 0.
C                IF KEY6 = 1 : ONLY OUTPUT ACCELERATION AND VELOCITY TIME
C                              HISTORIES ARE WRITTEN IN OFILE.A AND
C                              OFILE.V, RESPECTIVELY.
C                IF KEY6 = 2 : ONLY OUTPUT ACCELERATION AND DISPLACEMENT
C                              TIME HISTORIES ARE WRITTEN IN OFILE.A AND
C                              OFILE.D, RESPECTIVELY.
C                IF KEY6 = 3 : ALL OUTPUT ACCELERATION, VELOCITY AND
C                              DISPLACEMENT TIME HISTORIES ARE WRITTEN IN
C                              OFILE.A, OFILE.V AND OFILE.D, RESPECTIVELY.
C
C --- PARAMETERS FOR THE FUNCTION KEYS :
C
C --- SOIL RESPONSE : SKIP THIS GROUP 7 IF KEY1 = 0 !!!
C
C    7.1  DEN1, SV1, DAMP1, THICK, RD : FORMAT(FREE)
C         DEN1 IS THE SOIL DENSITY (GM/CC).
C         SV1 IS THE SHEAR WAVE VELOCITY OF THE SOIL (M/SEC).
C         DAMP1 IS THE DAMPING RATIO OF THE SOIL (PERCENT).
C         THICK IS THE THICKNESS OF THE SOIL LAYER (M).
C         RD IS THE RECEIVER DEPTH (DEPTH OF INTEREST) (M).
C            (RD MUST BE .LE. THICK).
C
C    7.2  DEN2, SV2 : FORMAT(FREE)
C         DEN2 IS THE BEDROCK DENSITY (GM/CC).
C         SV2 IS THE SHEAR WAVE VELOCITY OF THE BEDROCK (M/SEC).
C
C         *** NOTE : DENSITY UNITS IN DEN1 AND DEN2 CAN BE IN OTHER
C                    UNITS IF CONSISTENT !!!
C                    LENGTH UNITS IN THICK, RD, SV1 AND SV2 CAN BE IN
C                    OTHER UNITS IF CONSISTENT !!!
C
C --- NEAR-SITE AMPLIFICATION FACTORS : SKIP THIS GROUP 8 IF KEY2 = 0 !!!
C
C     8.  NAMP, AFREQ(I), AMFAC(I) : FORMAT(FREE)
C         NAMP IS THE NUMBER OF AMPLIFICATION FACTORS.
C         AFREQ(I) IS THE FREQUENCY AT WHICH AMPLIFICATION IS APPLIED
C                  (HERTZ).
C         AMFAC(I) IS THE AMPLIFICATION FACTOR AT AFREQ(I).
C
C         *** REPEAT (AFREQ(I),AMFAC(I)) PAIR NAMP TIMES. (MAXIMUM 100) !!!
C
C         *** NOTE : FOR FREQUENCY < AFREQ(1), AMFAC(1) IS USED.
C                    FOR FREQUENCY > AFREQ(NAMP), AMFAC(NAMP) IS USED.
C
C --- INPUT ACCELERATION TIME HISTORY : SKIP THIS GROUP 9 IF KEY5 .GE. 0 !!
C
C    9.1  AFILE : FORMAT(A80)
```

```
C

C         AFILE IS THE INPUT ACCELERATION TIME HISTORY FILE NAME.
C
C    9.2  NPT, NHEAD, DT, FMT : FORMAT(2I5,F10.4,A40)
C         NPT IS THE NUMBER OF POINTS IN THE INPUT ACCELERATION TIME
C             HISTORY. (MAXIMUM 4096).
C         NHEAD IS THE NUMBER OF HEADER CARDS IN THE INPUT ACCELERATION
C              TIME HISTORY.
C         DT IS THE TIME INCREMENT OF THE INPUT ACCELERATION TIME
C            HISTORY (SECONDS).
C         FMT IS THE READ FORMAT OF THE INPUT ACCELERATION TIME HISTORY.
C             DEFAULT IS (8F9.6).
C
C         *** NOTE : IF NPT < 2048, TRAILING ZEROS ARE AUTOMATICALLY
C                    ADDED TO DOUBLE THE NPT TO THE CLOSEST POWER OF
C                    2 POINTS.
C                    IF NPT > 2048, ONLY THE FIRST 2048 POINTS ARE USED,
C                    AND 2048 POINTS OF TRAILING ZEROS ARE AUTOMATICALLY
C                    ADDED TO THE TOTAL OF 4096 POINTS.
C
C --- OUTPUT TIME HISTORIES : SKIP THIS GROUP 10 IF KEY5 = 0 !!!
C
C   10.1  FACTA, FACTV, FACTD : FORMAT(FREE)
C         FACTA, FACTV & FACTD ARE THE NORMALIZING FACTORS FOR THE
C                OUTPUT ACCELERATION, VELOCITY & DISPLACEMENT TIME
C                HISTORIES, RESPECTIVELY.
C         IF FACTA,V,D = 0.0 : NO NORMALIZATION IS APPLIED.
C         IF FACTA,V,D < 0.0 : THE OUTPUT TIME HISTORIES ARE NORMALIZED
C                              TO THE COMPUTED PEAK VALUES BASED ON THE
C                              RANDOM VIBRATION THEORY, RESPECTIVELY.
C         IF FACTA,V,D > 0.0 : THE OUTPUT TIME HISTORIES ARE NORMALIZED
C                              TO FACTA,V,D, RESPECTIVELY.
C
C   10.2  NIT1, NIT2 : FORMAT(FREE)
C         NIT1 IS THE NUMBER OF ITERATIONS USED FOR RVT SPECTRAL MATCHING.
C         NIT2 IS THE NUMBER OF ITERATIONS USED FOR SDF SPECTRAL MATCHING.
C
C         *** NOTE : 2 TO 3 ITERATIONS FOR EACH CASE IS RECOMMENDED.
C
C --- DESIGN (TARGET) RESPONSE SPECTRUM : SKIP THIS GROUP 10.3
C                                         IF NIT1 AND NT2 = 0 !!!
C
C   10.3  NPSV, TFREQ(I), TSV(I) : FORMAT(FREE)
C         NPSV IS THE NUMBER OF DESIGN (TARGET) SPECTRAL VALUES.
C              (MAXIMUM 100).
C              IF NPSV > 0 : SPECTRAL VALUES (TSV(I)) MUST BE IN
C                            ACCELERATION (G'S).
C              IF NPSV < 0 : SPECTRAL VALUES (TSV(I)) MUST BE IN
C                            VELOCITY (CM/SEC).
C         TFREQ(I) IS THE DESIGN (TARGET) FREQUENCY (HERTZ).
C         TSV(I) IS THE DESIGN (TARGET) SPECTRAL VALUES AT TFREQ(I).
C
C         *** REPEAT (TFREQ(I),TSV(I)) PAIR ABS(NPSV) TIMES !!!
C
C         *** NOTE : SET THE DESIGN FREQUENCY RANGE BEYOND 0.1 TO 34.0
C                    HERTZ, IF POSSIBLE. I.E. SET TFREQ(1) .LE. 0.1 HZ
C                    AND TFREQ(NPSV) .GE. 34.0 HERTZ. THIS RANGE IS SET
```

```
C


C                   UP FOR INTERPOLATING THE DESIGN SPECTRAL VALUES AT
C                   THE OSCILLATOR FREQUENCY REGIME !!!
C
C --- FILTERING PARAMETERS FOR COMPUTING OUTPUT TIME HISTORIES
C
C   10.4  FC1, NF1, FC2, NF2 : FORMAT(FREE)
C         FC1 IS THE CORNER FREQUENCY OF THE FIRST BUTTERWORTH FILTER,
C             (-VE FOR REMOVAL). (HERTZ).
C         NF1 IS THE ORDER NUMBER (NO. OF POLES) OF THE FIRST
C             BUTTERWORTH FILTER. (-VE FOR HIGH PASS).
C         FC2 IS THE CORNER FREQUENCY OF THE SECOND BUTTERWORTH FILTER,
C             (-VE FOR REMOVAL). (HERTZ).
C         NF1 IS THE ORDER NUMBER (NO. OF POLES) OF THE SECOND
C             BUTTERWORTH FILTER. (-VE FOR HIGH PASS).
C
C --- E N D   O F   P R O G R A M
C
```

```
C
C --- PROGRAM  R A S C A L
C
C     PROGRAM RASCAL (RESPONSE SPECTRUM AND ACCELEROGRAM SCALING)
C     COMPUTES BRUNE FOURIER AMPLITUDE BASED ON THE METHOD SUGGESTED
C     BY J. N. BRUNE (BSSA, VOL. 75, SEPTEMBER 1970) AND COMPUTES PEAK
C     ACCELERATION, PEAK VELOCITY, RESPONSE SPECTRAL ACCELERATION AND
C     RESPONSE SPECTRAL VELOCITY BASED ON THE METHOD SUGGESTED BY D. M.
C     BOORE (BSSA, VOL. 73, DECEMBER 1983) BY USING RANDOM VIBRATION
C     THEORY (RVT) TECHNIQUES.
C
C     THE PROGRAM ALSO GENERATES SYNTHETIC TIME HISTORY (ACCELERATION,
C     VELOCITY OR DISPLACEMENT) BY COMPUTING THE FFT AND EXTRACTING THE
C     PHASE OF AN INPUT ACCELEROGRAM (INTERNAL OR EXTRENAL BASE) AND
C     COMBINES THE COMPUTED BRUNE FOURIER AMPLITUDE TO GENERATE THE
C     OUTPUT TIME HISTORIES.
C
C     THIS PROGRAM HAS THE CAPABILITY OF COMPUTING THE HALF-SPACE (ROCK
C     OUTCROP) OR SITE (SINGLE-LAYERED SOIL) RESPONSE AND OF GENERATING
C     OUTPUT VELOCITY OR DISPLACEMENT TIME HISTORY AS WELL.
C
C --- CODED BY KIN W. LEE, NOVEMBER, 1985.
C              WOODWARD-CLYDE CONSULTANTS, WALNUT CREEK OFFICE.
C
C
C
      CHARACTER*80  TITLE, OFILE, AFILE, WORD, FLAG(145)*1, FMT*40,
     &              FILE8, FILE9, FILE11, FILE12, FILE13, SUF8*4,
     &              SUF9*3, SUF11*2, SUF12*2, SUF13*2, CIT1*2, CIT*2
C
      REAL  MW
C
      DIMENSION  FREQ(145), FAS(145), RSA(145), RSV(145), PAA(145),
     &           PRV(145), TSVI(145), SPRAT(145), TFREQ(100), TSV(100)
C
      COMPLEX  RE, HS
C
      COMMON     SFREQ(5001), SFAS(5001), FUNXO(5001), FUNX2(5001),
     &           FUNX4(5001), SWI(5001), SPRATS(5001),
     &           CP(2050), SP(2050), OTH(4100)
C
      COMMON  /PIDATA/ PI, PI2
C
      COMMON  /FADATA/ KEY1, KEY2, C, FC, PIR, Q, FQ, ALPHA, FMAX, N2,
     &                 CAP, PICAP
C
      COMMON  /AMDATA/ AFREQ(100), AMFAC(100), NAMP
C
      COMMON  /SMDATA/ SV1, DAMP1, THICK, ARATIO, RD, RK, CK
C
      COMMON  /TMDATA/ NPIA, NPT, NPT2, NP2, NPFR, DT,
     &                 A(4100), PFREQ(2050), PFAS(2050)
C
      COMMON /SPDATA/ DAMP, NFREQ, WI(145), PER(145)
C
C --- OSCILLATOR (WCC) FREQUENCY REGIME
```

```
C


C
      DATA  FREQ/0.001, 0.0999,
     &           0.100, 0.111, 0.125, 0.143, 0.167, 0.182, 0.200,
     &           0.222, 0.250, 0.263, 0.278, 0.294, 0.300, 0.312,
     &           0.333, 0.357, 0.385, 0.400, 0.417, 0.455, 0.500,
     &           0.556, 0.600, 0.625, 0.667, 0.700, 0.714, 0.769,
     &           0.800, 0.833, 0.900, 0.909, 1.000, 1.100, 1.111,
     &           1.176, 1.200, 1.250, 1.300, 1.333, 1.400, 1.429,
     &           1.471, 1.500, 1.515, 1.562, 1.600, 1.613, 1.667,
     &           1.700, 1.724, 1.786, 1.800, 1.852, 1.900, 1.923,
     &           2.000, 2.083, 2.100, 2.174, 2.200, 2.273, 2.300,
     &           2.381, 2.400, 2.500, 2.600, 2.632, 2.700, 2.778,
     &           2.800, 2.900, 2.941, 3.000, 3.125, 3.155, 3.300,
     &           3.333, 3.448, 3.571, 3.600, 3.800, 3.850, 4.000,
     &           4.167, 4.200, 4.400, 4.550, 4.600, 4.800, 5.000,
     &           5.250, 5.263, 5.500, 5.556, 5.750, 5.882, 6.000,
     &           6.250, 6.500, 6.667, 6.750, 7.000, 7.143, 7.250,
     &           7.500, 7.692, 7.750, 8.000, 8.333, 8.500, 9.000,
     &           9.091, 9.500, 10.000, 10.500, 11.000, 11.111, 11.500,
     &           11.765, 12.000, 12.500, 13.000, 13.333, 13.500, 14.000,
     &           14.286, 14.500, 15.000, 15.385, 16.000, 16.667, 17.000,
     &           18.000, 18.868, 20.000, 22.000, 25.000, 28.000, 29.412,
     &           31.000, 33.333, 34.000/
C
C
      READ(5,1100) TITLE
      READ(5,1100) OFILE
      READ(5,*) SDROP, DENS, D, H, SV
      READ(5,*) Q, FQ, ALPHA, MW
      READ(5,*) DAMP, FMAX, N, CAP
      READ(5,*) KEY1, KEY2, KEY3, KEY4, KEY5, KEY6
C
      PRINT 1200, TITLE
      PRINT 1300, OFILE
      PRINT 1340, SDROP, DENS, D, H, SV, Q, FQ, ALPHA, MW, DAMP,
     &            FMAX, N, CAP, KEY1, KEY2, KEY3, KEY4, KEY5, KEY6
C
C --- FUNCTIONAL KEY1 OPERATION
C
      PRINT 1200, TITLE
      PRINT 1400
C
      IF ( KEY1 .EQ. 0 ) THEN
         PRINT 1410
      ELSE
         READ(5,*) DEN1, SV1, DAMP1, THICK, RD
         READ(5,*) DEN2, SV2
C
         ARATIO = ( DEN1 * SV1 ) / ( DEN2 * SV2 )
         PRINT 1420
         PRINT 1430, DEN1, SV1, DAMP1, THICK, RD, DEN2, SV2
         DAMP1 = DAMP1 / 100.0
      END IF
C
C --- FUNCTIONAL KEY2 OPERATION
C
```

```
C
      IF ( KEY2 .EQ. 0 ) THEN
         PRINT 1440
      ELSE
         READ(5,*) NAMP, ( AFREQ(I), AMFAC(I), I=1,NAMP )
         PRINT 1460
         DO 120, I=1,NAMP
  120    PRINT 1480, I, AFREQ(I), AMFAC(I)
      END IF
C
C --- INITIALIZES CONSTANT PARAMETERS
C
      NFREQ = 145
      AMPF = 1.0
      DAMP = DAMP / 100.0
      DAMP2 = DAMP * 2.0
      N2 = N * 2
      PI = 3.141592653589793
      PI2 = 2.0 * PI
      PICAP = PI * CAP
      SRHPI = SQRT( 0.5 * PI )
      EULER = 0.5772156649
C
      SDAMP = 100.0 / ( 2.0 * Q )
      FC = 21.07 * SV * ( SDROP ** ( 1.0 / 3.0 ) ) * EXP(-1.15 * MW)
      SR = ( 2.34 * SV ) / ( PI2 * FC )
      R = SQRT( D * D + H * H )
C
C --- FUNCTIONAL KEY3 OPERATION
C
      ATTEN = 1.0 / R
      IF ( R .GT. 100.0 .AND. KEY3 .EQ. 1 ) THEN
         ATTEN = 0.1 / SQRT(R)
         PRINT 1500, ATTEN
      ELSE
         PRINT 1520, ATTEN
      END IF
C
      C = ( 7.8 * SDROP * SR * ATTEN ) / ( DENS * SV )
C
C --- FUNCTIONAL KEY4 OPERATION
C
      HERR = 0.0
      IF ( KEY4 .EQ. 0 ) THEN
         PRINT 1540
      ELSE
         HERR = 0.05 * R
         PRINT 1560, HERR
      END IF
C
      DRVT = 1.0 / FC + HERR
      PRINT 1580, DRVT
C
C --- FUNCTIONAL KEY5 OPERATION
C
      NP2 = 12
      NPT2 = 4098
```

```
C
      NPT = 4096
      NHEAD = 3
      DT = 0.01
      FMT = '(8F9.6)'
C
      NPFR = 2049
      PFR1 = 0.0244141
      DPFR = PFR1
C
      FACTA = 0.0
      FACTV = 0.0
      FACTD = 0.0
C
      TSVMX = 0.0
      DO 130 I=1,NFREQ
  130 TSVI(I) = 0.0
C
      IF ( KEY5 ) 190, 140, 160
C
C --- KEY5 = 0 : NO GENERATION OF SYNTHETIC ACCELERATION TIME HISTORY
C
  140 PRINT 1600
      NIT1 = 0
      NIT = 0
      GO TO 340
C
C --- KEY5 > 0 : GENERATION OF SYNTHETIC ACCELERATION TIME HISTORY BASED
C                ON A BUILT-IN ACCELERATION TIME HISTORY
C
  160 PRINT 1620, KEY5
C
C --- CHOOSES A BUILT-IN ACCELERATION TIME HISTORY BASED ON MW AND R
C     RANGES
C
      IF ( MW .LE. 4.5 ) THEN
         IF ( R .LE. 30.0 ) THEN
            AFILE = 'M4.NF.DATA'
            NPIA = 1320
            GO TO 170
         ELSE
            AFILE = 'M4.FF.DATA'
            NPIA = 1320
            GO TO 170
         END IF
      END IF
C
      IF ( MW .GT. 4.5 .AND. MW .LE. 5.5 ) THEN
         IF ( R .LE. 30.0 ) THEN
            AFILE = 'M5.NF.DATA'
            NPIA = 1320
            GO TO 170
         ELSE
            AFILE = 'M5.FF.DATA'
            NPIA = 2048
            GO TO 170
         END IF
```

```
C

      END IF
C
      IF ( MW .GT. 5.5 .AND. MW .LE. 6.5 ) THEN
         IF ( R .LE. 30.0 ) THEN
            AFILE = 'M6.NF.DATA'
            NPIA = 2048
            GO TO 170
         ELSE
            AFILE = 'M6.FF.DATA'
            NPIA = 2048
            GO TO 170
         END IF
      END IF
C
      IF ( R .LE. 30.0 ) THEN
         AFILE = 'M7.NF.DATA'
         NPIA = 2048
      ELSE
         AFILE = 'M7.FF.DATA'
         NPIA = 2048
      END IF
C
  170 OPEN(7, FILE=AFILE)
      DO 180 I=1,NHEAD
      READ(7,1100) WORD
  180 PRINT 1680, WORD
      READ(7,FMT) ( A(I), I=1,NPIA )
      CLOSE(7)
      PRINT 1640, AFILE, MW, R, NPIA, DT
      GO TO 280
C
C --- KEYS < 0 : GENERATION OF SYNTHETIC ACCELERATION TIME HISTORY BASED
C                ON THE INPUT ACCELERATION TIME HISTORY
C
  190 PRINT 1660, KEYS
C
      READ(5,1100) AFILE
      READ(5,1700) NPIA, NHEAD, DT, FMT
      PRINT 1640, AFILE, MW, R, NPIA, DT
C
      IF ( NPIA .GT. 2048 ) THEN
         NPIA = 2048
         PRINT 1710
      END IF
C
      IF ( FMT .EQ. '          ' ) FMT = '(8F9.6)'
C
      OPEN(7, FILE=AFILE)
      DO 220 I=1,NHEAD
      READ(7,1100) WORD
  220 PRINT 1680, WORD
      READ(7,FMT) ( A(I), I=1,NPIA)
      CLOSE(7)
C
C --- REDEFINE NPT IF NPIA < 2048
C
```

```
C

      NP2 = NINT( ALOG(FLOAT(NPIA)) / ALOG(2.0) + 0.5 )
      NP2 = NP2 + 1
      IF ( NP2 .GT. 12 ) THEN
         PRINT 1720, NP2
         NP2 = 12
      END IF
C
      NPT = 2 ** NP2
      NPT2 = NPT + 2
C
      NPFR = NPT / 2 + 1
      PFR1 = 1.0 / ( NPT * DT )
      DPFR = PFR1
C
C --- DETERMINES THE NYQUIST FREQUENCY OF THE INPUT ACCELERATION TIME
C     HISTORY AND THE UPPER LIMIT OF THE RESPONSE SPECTRAL FREQUENCY
C     BY TAKING 70 % OF THE NYQUIST FREQUENCY.
C
      FNYQ = 0.5 / DT
      FNYQ = 0.7 * FNYQ
      IF ( FNYQ .LT. 34.0 ) THEN
         DO 240 K=1,NFREQ
         IF ( FNYQ .LT. FREQ(K) ) GO TO 260
  240    CONTINUE
  260    NFREQ = K - 1
      END IF
C
  280 PRINT 1730, NPFR, PFR1, DPFR
C
C --- READS IN NORMALIZING FACTORS, OR DESIGN (TARGET) RESPONSE SPECTRUM
C
      READ(5,*) FACTA, FACTV, FACTD
      PRINT 1740, FACTA, FACTV, FACTD
C
      READ(5,*) NIT1, NIT2
      NIT = NIT1 + NIT2
      PRINT 1750, NIT, NIT1, NIT2
C
      IF ( NIT .EQ. 0 ) GO TO 340
C
      PRINT 1200, TITLE
      PRINT 1760
      READ(5,*) NPSV, ( TFREQ(I), TSV(I), I=1,ABS(NPSV) )
C
      IF ( NPSV .GT. 0 ) THEN
         PRINT 1770
      ELSE
         PRINT 1780
      END IF
C
      DO 300 I=1,ABS(NPSV)
  300 PRINT 1480, I, TFREQ(I), TSV(I)
C
C --- INTERPOLATES DESIGN (TARGET) RESPONSE SPECTRUM, TSV AT THE
C     OSCILLATOR FREQUENCY, FREQ(I)
C
```

```
C
      DO 320 I=1,NFREQ
      CALL INTERP( TFREQ, TSV, ABS(NPSV), FREQ(I), BSV )
      TSVI(I) = BSV
      IF ( TSVMX .LE. TSVI(I) ) TSVMX = TSVI(I)
  320 CONTINUE
C
C --- INITIALIZES NUMBER OF ITERATIONS TO SUFFIXES, CIT1 AND CIT
C
  340 OPEN(21, STATUS='SCRATCH')
      WRITE(21,'(2I2)') NIT1, NIT
      REWIND 21
      READ(21,'(2A2)') CIT1, CIT
      IF ( CIT1(1:1) .EQ. ' ' ) CIT1(1:1) = '0'
      IF ( CIT(1:1) .EQ. ' ' ) CIT(1:1) = '0'
      CLOSE(21)
C
C --- FUNCTIONAL KEY6 OPERATION
C
      I = INDEX(OFILE, ' ')
C
      K = 1
      SUF8 = '.RVT'
      FILE8 = OFILE(1:I-1)//SUF8//CIT1
      OPEN(8, FILE=FILE8)
C
      IF ( KEY5 .EQ. 0 ) THEN
         PRINT 1790, FILE8
         GO TO 400
      END IF
C
      PRINT 1800, KEY6
      PRINT 1820, K, FILE8
C
      K = K + 1
      SUF9 = '.SP'
      FILE9 = OFILE(1:I-1)//SUF9//CIT
      PRINT 1820, K, FILE9
      OPEN(9, FILE=FILE9)
C
      K = K + 1
      SUF11 = '.A'
      FILE11 = OFILE(1:I-1)//SUF11//CIT
      PRINT 1820, K, FILE11
      OPEN(11, FILE=FILE11)
C
      IF ( KEY6 .EQ. 0 ) GO TO 390
C
      GO TO ( 360, 380, 360 ) KEY6
C
  360 K = K + 1
      SUF12 = '.V'
      FILE12 = OFILE(1:I-1)//SUF12//CIT
      PRINT 1820, K, FILE12
      OPEN(12, FILE=FILE12)
      IF ( KEY6 .NE. 3 ) GO TO 390
C
```

```
C



  380 K = K + 1
      SUF13 = '.D'
      FILE13 = OFILE(1:I-1)//SUF13//CIT
      PRINT 1820, K, FILE13
      OPEN(13, FILE=FILE13)
C
  390 READ(5,*) FC1, NF1, FC2, NF2
      PRINT 1830, FC1, NF1, FC2, NF2
C
C
  400 CONTINUE
C
      PRINT 1200, TITLE
      PRINT 1840, SDAMP, FC, SR, R
C
      PIR = PI * R / SV
      C = C / 981.0
C
C --- INITIALIZES RELATED ARRAYS, BASICALLY FOR PEAK ACCELERATION AND
C     VELOCITY COMPUTATIONS
C
      DO 420 I=1,NFREQ
      FAS(I) = 0.0
      RSA(I) = 0.0 .
      RSV(I) = 0.0
      SPRAT(I) = 1.0
      PER(I) = 0.0
      FLAG(I) = ' '
  420 CONTINUE
C
      DO 440 I=3,NFREQ
      PER(I) = 1.0 / FREQ(I)
      WI(I) = PI2 * FREQ(I)
  440 CONTINUE
C
C --- COMPUTES FOURIER AMPLITUDE, FAS IN THE OSCILLATOR FREQUENCY REGIME
C
      CALL BRUNE( 3, NFREQ, FREQ, FAS )
C
C --- COMPUTES FOURIER AMPLITUDE, SFAS IN THE BRUNE'S OR INTEGRATION
C     FREQUENCY REGIME
C
      NSFR = 5001
      SFR1 = 0.0001
      DSFR = 0.01
C
      DO 500 I=1,NSFR
      SFREQ(I) = SFR1 + DSFR * FLOAT( I - 1 )
      SWI(I) = PI2 * SFREQ(I)
      SPRATS(I) = 1.0
  500 CONTINUE
C
      CALL BRUNE( 1, NSFR, SFREQ, SFAS )
C
C
C --- COMPUTES RESPONSE SPECTRAL ACCELERATION, RSA AND VELOCITY, RSV
```

```
C
C     BY RANDOM VIBRATION THEORY (RVT) FOR NIT1 NUMBER OF ITERATIONS
C
      PRINT 1860
C
C --- INITIALIZES MAXIMUM VALUES
C
      FASMX = 0.0
      RSAMX = 0.0
      RSVMX = 0.0
      SPRMX = 0.0
C
      DO 860 IT=1, NIT1 + 1
C
C --- UPDATES SFAS(I) WITH NEW SPRATS(I)
C
      DO 620 I=1,NSFR
      SFAS(I) = SFAS(I) * SPRATS(I)
  620 CONTINUE
C
      DO 800 I=1,NFREQ
C
C --- UPDATES FAS(I) WITH NEW SPRAT(I)
C
      FAS(I) = FAS(I) * SPRAT(I)
      IF ( FASMX .LE. FAS(I) ) FASMX = FAS(I)
C
      IF ( I .LE. 2 ) THEN
         FDRVT = DRVT
         GO TO 640
      END IF
C
C ------- COMPUTES FDRVT FACTOR, FREQUENCY DEPENDENT DURATON OF THE
C         SOURCE EXCITATION IN THE RANDOM VIBRATION THEORY
C
      RATIO = FREQ(I) * DRVT
      RATIO3 = RATIO * RATIO * RATIO
      RATIO4 = RATIO3 / ( RATIO3 + 1.0 / 3.0 )
      FDRVT = DRVT + RATIO4 / ( WI(I) * DAMP )
C
C ------- COMPUTES OSCILLATOR TRANSFER FUNCTION, H(FREQ,SFREQ)
C
      FREQ2 = FREQ(I) * FREQ(I)
      FREQ4 = FREQ2 * FREQ2
C
  640 DO 700 J=1,NSFR
      SFAS2 = SFAS(J) * SFAS(J)
      SWI2 = SWI(J) * SWI(J)
C
C --- SETS H2 = 1.0 TO COMPUTE PEAK ACCELERATION, AMAX
C
      IF ( I .EQ. 1 ) THEN
         H2 = 1.0
         GO TO 680
      END IF
C
C --- SETS H2 = 1.0 / SWI2 TO COMPUTE PEAK VELOCITY, VMAX
```

```
C


C
      IF ( I .EQ. 2 ) THEN
         H2 = 1.0 / SWI2
         GO TO 680
      END IF
C
      FACT1 = FREQ2 - SFREQ(J) * SFREQ(J)
      FACT2 = DAMP2 * FREQ(I) * SFREQ(J)
      H2 = FREQ4 / ( FACT1 * FACT1 + FACT2 * FACT2 )
C
  680 FUNX0(J) = SFAS2 * H2
      FUNX2(J) = FUNX0(J) * SWI2
      FUNX4(J) = FUNX2(J) * SWI2
C
  700 CONTINUE
C
C ------- INTEGRATES THE OSCILLATOR TRANSFER FUNCTION BY SIMPSON'S RULE
C
      CALL SIMPS( NSFR-1, DSFR, FUNX0, SM0 )
      SM0 = SM0 * 2.0
      ARVT = SQRT( SM0 / FDRVT )
C
      CALL SIMPS( NSFR-1, DSFR, FUNX2, SM2 )
      SM2 = SM2 * 2.0
      PFZ = SQRT( SM2 / SM0 ) / PI2
      SNZ = 2.0 * PFZ * DRVT
C
      IF ( SNZ .LT. 2.0 ) THEN
         FLAG(I) = '*'
         SNZ = 2.0
      END IF
C
      CALL SIMPS( NSFR-1, DSFR, FUNX4, SM4 )
      SM4 = SM4 * 2.0
      PFE = SQRT( SM4 / SM2 ) / PI2
      SNE = 2.0 * PFE * DRVT
C
      IF ( SNE .LT. 2.0 ) THEN
         FLAG(I) = '*'
         SNE = 2.0
      END IF
C
C     COMPUTES QFACT, THE RATIO OF AMAX TO ARVT.
C
      IF ( SNE .LT. 20.0 ) THEN
C
         NE = INT(SNE)
         BAND = SM2 / SQRT( SM0 * SM4 )
         BANDL = 1.0
         SUM = 0.0
         SIGN = 1.0
C
         DO 720 L=1,NE
         BANDL = BANDL * BAND
C
         SUM = SUM + SIGN * BINOM(L,NE) * BANDL / SQRT( FLOAT(L) )
```

```
C



C
          SIGN = SIGN * (-1.0)
  720     CONTINUE
C
          QFACT = SRHPI *  SUM
C
       ELSE
          QFAC = SQRT( 2.0 * ALOG(SNZ) )
          QFACT = QFAC + EULER / QFAC
       END IF
C
       IF ( I .EQ. 1 ) THEN
          PFEA = PFE
          PFZA = PFZ
          SNEA = SNE
          SNZA = SNZ
          ARVTA = ARVT
          AMAX = ARVT * QFACT
          GO TO 800
       END IF
C
       IF ( I .EQ. 2 ) THEN
          PFEV = PFE
          PFZV = PFZ
          SNEV = SNE
          SNZV = SNZ
          ARVTV = ARVT * 981.0
          VMAX = ARVTV * QFACT
          GO TO 800
       END IF
C
       RSA(I) = ARVT * QFACT
       IF ( RSAMX .LE. RSA(I) ) RSAMX = RSA(I)
       RSV(I) = RSA(I) / WI(I) * 981.0
       IF ( RSVMX .LE. RSV(I) ) RSVMX = RSV(I)
C
  800  CONTINUE
C
       PRINT 1880, IT-1, AMAX, ARVTA, PFEA, PFZA, VMAX, ARVTV, PFEV, PFZV
C
       IF ( KEY5 .EQ. 0 .OR. NIT1 .EQ. 0 ) GO TO 860
C
C ---  COMPUTES SPECTRAL RATIO IN THE OSCILLATOR FREQUENCY REGIME
C
       DO 820 I=3,NFREQ
C
       IF ( NPSV .GT. 0 ) THEN
          SPRAT(I) = TSVI(I) / RSA(I)
       ELSE
          SPRAT(I) = TSVI(I) / RSV(I)
       END IF
C
       IF ( SPRMX .LE. SPRAT(I) ) SPRMX = SPRAT(I)
C
  820  CONTINUE
C
```

```
C
C --- INTERPOLATES SPECTRAL RATIO, SPRAT AT THE INTEGRATION FREQUENCY,
C     SFREQ(I)
C
      DO 840 I=1,NSFR
      CALL INTERB( FREQ, SPRAT, NFREQ, SFREQ(I), BSPRAT )
      SPRATS(I) = BSPRAT
  840 CONTINUE
C
  860 CONTINUE
C
C
C --- PRINTS AND WRITES RVT SPECTRAL VALUES OF THE LAST ITERATION
C
      PRINT 1900
      PRINT 1200, TITLE
      WRITE(8,1100) TITLE
      WRITE(8,1100) TITLE
      WRITE(8,1920) NFREQ-2, DAMP, NIT1
      PRINT 1940, DAMP*100.0, NIT1
      PRINT 1950
C
      IF ( NPSV .GT. 0 ) THEN
         PRINT 1960
      ELSE
         PRINT 1970
      END IF
C
      NLINE = 10
      DO 870 I=3,NFREQ
      PRINT 1980, I-2, FREQ(I), FAS(I), RSA(I), RSV(I), TSVI(I),
     &             SPRAT(I), PER(I), FLAG(I)
      WRITE(8,2000) PER(I), FAS(I), RSA(I), RSV(I), TSVI(I), SPRAT(I)
      NLINE = NLINE + 1
C
      IF ( NLINE .GE. 60) THEN
         PRINT 1200, TITLE
         PRINT 1940, DAMP*100.0, NIT1
         PRINT 1950
C
         IF ( NPSV .GT. 0 ) THEN
            PRINT 1960
         ELSE
            PRINT 1970
         END IF
C
         NLINE = 10
      END IF
C
  870 CONTINUE
C
      CLOSE(8)
      PRINT 2020, FASMX, RSAMX, RSVMX, TSVMX, SPRMX
C
      IF ( KEY5 .EQ. 0 ) GO TO 999
C
      IF ( NIT1 .EQ. 0 ) GO TO 890
```

```
C



C
C --- UPDATES SFAS WITH THE LAST SPRATS
C
      DO 880 I=1,NSFR
      SFAS(I) = SFAS(I) * SPRATS(I)
  880 CONTINUE
C
C --- COMPUTES PHASE FREQUENCY, PFREQ(I) AND INTERPOLATES SFAS AT
C     PFREQ(I) FOR INPUTTING TO SUBROUTINE TIME
C
  890 DO 900 I=1,NPFR
      PFREQ(I) = PFR1 + DPFR * FLOAT( I - 1 )
      CALL INTERP( SFREQ, SFAS, NSFR, PFREQ(I), BFAS )
      PFAS(I) = BFAS
  900 CONTINUE
C
C --- EXTRACTS THE PHASE OF THE INPUT ACCELERATION TIME HISTOYR
C
      CALL TIME( -1, 0.0, 0, 0.0, 0, CP, SP, OTH, OTHMX )
C
C --- COMPUTES OUTPUT ACCELERATION TIME HISTORY AND RESPONSE SPECTRUM
C     OF A SINGLE-DEGREE-OF-FREEDOM SYSTEM (SDF) FOR NIT2 ITERATIONS
C
      DO 902 I=1,NFREQ
      PAA(I) = 0.0
      PRV(I) = 0.0
  902 CONTINUE
C
      DO 912 IT=1, NIT2+1
C
      PAAMX = 0.0
      PRVMX = 0.0
      SPRMX = 0.0
      FACTOR = 1.0
C
      IF ( IT .LT. NIT2+1 ) THEN
         CALL TIME( 0, 0.0, 0, 0.0, 0, CP, SP, OTH, OTHMX )
      ELSE
         CALL TIME( 0, FC1, NF1, FC2, NF2, CP, SP, OTH, OTHMX )
C
         IF ( FACTA .EQ. 0.0 ) GO TO 906
C
         IF ( FACTA .GT. 0.0 ) THEN
            FACTOR = FACTA / OTHMX
            OTHMX = FACTA
         ELSE
            FACTOR = AMAX / OTHMX
            OTHMX = AMAX
         END IF
      END IF
C
      DO 904 I=1,NPT
  904 OTH(I) = OTH(I) * FACTOR
C
  906 CALL SPECT( NPT, DT, OTH, PAA, PRV )
C
```

```
C
      DO 908 I=3,NFREQ
C
      FAS(I) = FAS(I) * SPRAT(I)
C
      IF ( PAAMX .LE. PAA(I) ) PAAMX = PAA(I)
      IF ( PRVMX .LE. PRV(I) ) PRVMX = PRV(I)
C
      IF ( NIT2 .EQ. 0 ) GO TO 908
C
      IF ( NPSV .GT. 0 ) THEN
         SPRAT(I) = TSVI(I) / PAA(I)
      ELSE
         SPRAT(I) = TSVI(I) / PRV(I)
      END IF
C
      IF ( SPRMX .LE. SPRAT(I) ) SPRMX = SPRAT(I)
C
  908 CONTINUE
C
      IF ( IT .EQ. NIT2+1 ) GO TO 912
C
      DO 910 I=1,NPFR
      CALL INTERB( FREQ, SPRAT, NFREQ, PFREQ(I), BSPRAT )
      PFAS(I) = PFAS(I) * BSPRAT
  910 CONTINUE
C
  912 CONTINUE
C
C --- UPDATES FOURIER AMPLITUDE, FAS IN THE OSCILLATOR FREQUENCY REGIME
C     BY BUTTERWORTH FILTERING.
C
      FASMX = 0.0
C
      DO 914 I=3,NFREQ
C
      RE = CMPLX( 1.0, 0.0 )
      HS = RE
C
C --- COMPUTES THE FIRST BUTTERWORTH FILTER.
C
      CALL BWORTH( FREQ(I), FC1, NF1, HS )
      IF ( FC1 .LT. 0.0 ) HS = 1.0 / HS
      RE = RE * HS
C
C --- COMPUTES THE SECOND BUTTERWORTH FILTER.
C
      CALL BWORTH( FREQ(I), FC2, NF2, HS )
      IF ( FC2 .LT. 0.0 ) HS = 1.0 / HS
      RE = RE * HS
C
      FAS(I) = FAS(I) * CABS(RE)
      IF ( FASMX .LE. FAS(I) ) FASMX = FAS(I)
C
  914 CONTINUE
C
C --- PRINTS AND WRITES SDF SPECTRAL VALUES OF THE LAST ITERATION
```

```
C


C
      PRINT 1200, TITLE
      WRITE(9,1100) TITLE
      WRITE(9,1100) TITLE
      WRITE(9,1920) NFREQ-2, DAMP, NIT
      PRINT 2040, DAMP*100.0, NIT
      PRINT 2050
C
      IF ( NPSV .GT. 0 ) THEN
         PRINT 1960
      ELSE
         PRINT 1970
      END IF
C
      NLINE = 10
      DO 916 I=3,NFREQ
      PRINT 1980, I-2, FREQ(I), FAS(I), PAA(I), PRV(I), TSVI(I),
     &              SPRAT(I), PER(I)
      WRITE(9,2000) PER(I), FAS(I), PAA(I), PRV(I), TSVI(I), SPRAT(I)
      NLINE = NLINE + 1
C
      IF ( NLINE .GE. 60) THEN
         PRINT 1200, TITLE
         PRINT 2040, DAMP*100.0, NIT
         PRINT 2050
C
         IF ( NPSV .GT. 0 ) THEN
            PRINT 1960
         ELSE
            PRINT 1970
         END IF
C
         NLINE = 10
      END IF
C
  916 CONTINUE
C
      CLOSE(9)
      PRINT 2020, FASMX, PAAMX, PRVMX, TSVMX, SPRMX
C
C --- WRITES OUTPUT ACCELERATION TIME HISTORY
C
      PRINT 1200, TITLE
      PRINT 2200
C
      WRITE(11,1100) TITLE
      WRITE(11,3000) NIT
      PRINT 3100, FILE11, NPT, DT, OTHMX
      WRITE(11,3200) NPT, DT, OTHMX
      WRITE(11,3400) ( OTH(I), I=1,NPT )
      CLOSE(11)
C
      IF ( KEY6 .EQ. 0 ) GO TO 999
C
      FACTA = FACTOR
C
```

```
C
      DO 918 I=1,NPFR
      PFAS(I) = PFAS(I) * 981.0
  918 CONTINUE
C
      GO TO ( 920, 930, 920 ) KEY6
C
C --- COMPUTES OUTPUT VELOCITY TIME HISTORY
C
  920 CALL TIME( 1, FC1, NF1, FC2, NF2, CP, SP, OTH, OTHMX )
C
      WRITE(12,1100) TITLE
      WRITE(12,4000) NIT
C
      IF ( FACTV .EQ. 0.0 ) GO TO 924
C
      IF ( FACTV .GT. 0.0 ) THEN
         FACTOR = FACTV / OTHMX
         OTHMX = FACTV
      ELSE
         FACTOR = VMAX / OTHMX
         OTHMX = VMAX
      END IF
C
      DO 922 I=1,NPT
  922 OTH(I) = OTH(I) * FACTOR
C
  924 PRINT 4100, FILE12, NPT, DT, OTHMX
      WRITE(12,4200) NPT, DT, OTHMX
      WRITE(12,3400) ( OTH(I), I=1,NPT )
      CLOSE(12)
C
C --- COMPUTES OUTPUT DISPLACEMENT TIME HISTORY
C
  930 CALL TIME( 2, FC1, NF1, FC2, NF2, CP, SP, OTH, OTHMX )
C
      WRITE(13,1100) TITLE
      WRITE(13,5000) NIT
C
      IF ( FACTD .EQ. 0.0 ) GO TO 934
C
      IF ( FACTD .GT. 0.0 ) THEN
         FACTOR = FACTD / OTHMX
         OTHMX = FACTD
      ELSE
         FACTOR = FACTA
         OTHMX = OTHMX * FACTOR
      END IF
C
      DO 932 I=1,NPT
  932 OTH(I) = OTH(I) * FACTOR
C
  934 PRINT 5100, FILE13, NPT, DT, OTHMX
      WRITE(13,5200) NPT, DT, OTHMX
      WRITE(13,3400) ( OTH(I), I=1,NPT )
      CLOSE(13)
C
```

```
C


  999 PRINT 9990
C
      STOP
C
C
C --- FORMAT STATEMENTS
C
 1100 FORMAT(A80)
 1200 FORMAT('1',//5X,'*** ',A80)
 1300 FORMAT(//5X,'*** COMMON OUTPUT FILE NAME :  ',A80)
 1340 FORMAT(//5X,'*** INPUT PARAMETERS ***',
     &       //9X,'*** SOURCE INFORMATION ***',
     &       //5X,'STRESS DROP ......................  ',F10.3,' BARS',
     &       //5X,'MEDIUM DENSITY ...................  ',F10.3,' GM/CC',
     &       //5X,'EPICENTRAL DISTANCE ..............  ',F10.3,' KM',
     &       //5X,'SOURCE DEPTH .....................  ',F10.3,' KM',
     &       //5X,'SHEAR WAVE VELOCITY ..............  ',F10.3,' KM/SEC',
     &       //5X,'QUALITY FACTOR, Q ................  ',F10.3,
     &       //5X,'CONTROL FREQUENCY FOR Q FACTOR....  ',F10.3,' HZ',
     &       //5X,'EXPONENTIAL CONSTANT FOR Q .......  ',F10.3,
     &       //5X,'MOMENT MAGNITUDE .................  ',F10.3,
     &       //5X,'SPECTRAL DAMPING .................  ',F10.3,' %',
     &       //5X,'FMAX CORNER FREQUENCY ............  ',F10.3,' HZ',
     &       //5X,'FMAX ORDER NUMBER ................  ',I10,
     &       //5X,'EXPONENTIAL FILTERING CONSTANT....  ',F10.3
     &       //5X,'KEY1 ..............................',I10,
     &       //5X,'KEY2 ..............................',I10,
     &       //5X,'KEY3 ..............................',I10,
     &       //5X,'KEY4 ..............................',I10,
     &       //5X,'KEY5 ..............................',I10,
     &       //5X,'KEY6 ..............................',I10)
 1400 FORMAT(//5X,'*** FUNCTIONAL KEY INFORMATION ***')
 1410 FORMAT(//5X,'*** KEY1 = 0 :  HALF-SPACE RESPONSE IS COMPUTED')
 1420 FORMAT(//5X,'*** KEY1 = 1 :  SITE RESPONSE IS COMPUTED')
 1430 FORMAT(//20X,'*** SITE INFORMATION ***',
     &       //24X,'DENSITY',6X,'SV',5X,'DAMPING',5X,'THICK',5X,'DEPTH',
     &        /24X,'(GM/CC)',3X,'(M/SEC)',5X,'(%)',8X,'(M)',7X,'(M)',
     &        /16X,55('-'),//16X,'SOIL  ',5F10.3,//16X,'ROCK  ',2F10.3)
 1440 FORMAT(//5X,'*** KEY2 = 0 :  NO FREQUENCY DEPENDENT AMPLIFICATION',
     &             ' FACTORS ARE APPLIED')
 1460 FORMAT(//5X,'*** KEY2 = 1 :  FREQUENCY DEPENDENT AMPLIFICATION',
     &             ' FACTORS ARE APPLIED :',//29X,'FREQ. ',6X,'AMP. ',
     &             /22X,'NO. ',3X,'(HERTZ)',4X,'FACTOR',/22X,23('-'),/)
 1480 FORMAT(/20X,I5,2F10.4)
 1500 FORMAT(//5X,'*** KEY3 = 1 :  ATTEN = 0.1 / SQRT(R) = ',F10.6,
     &            '    FOR R > 100 KM.')
 1520 FORMAT(//5X,'*** KEY3 = 0 :  ATTEN = 1.0 / R = ',F10.6)
 1540 FORMAT(//5X,'*** KEY4 = 0 :  HERRMANN''S TERM, HERR = 0.0')
 1560 FORMAT(//5X,'*** KEY4 = 1 :  HERRMANN''S TERM, HERR = 0.05 * R = ',
     &            F1C.4)
 1580 FORMAT(//20X,'*** SOURCE EXCITATION DURATION, DRVT = 1.0 / FC',
     &             ' + HERR = ',F10.4,'  SECONDS')
 1600 FORMAT(//5X,'*** KEY5 AND KEY6 = 0 :  NO SYNTHETIC ACCELERATION',
     &             ' TIME HISTORY IS GENERATED')
 1620 FORMAT(//5X,'*** KEY5 = ',I2,' :  SYNTHETIC ACCELERATION TIME',
     &             ' HISTORY IS GENERATED BASED ON A BUILT-IN',
```

```
C

     &              ' ACCELERATION TIME HISTORY')
1640 FORMAT(//21X,'*** INPUT ACCELERATION TIME HISTORY FILE :  ',A80,
     &        //25X,'FOR      MW = ',F5.3,'  AND   R = ',F10.3,' KM.',
     &        //25X,'WITH  NPIA = ',I5,'  AND  DT = ',F10.3,' SEC.')
1660 FORMAT(//5X,'*** KEY5 = ',I2,' : SYNTHETIC ACCELERATION TIME',
     &              ' HISTORY IS GENERATED BASED ON THE INPUT',
     &              ' ACCELERATION TIME HISTORY')
1680 FORMAT(/25X,'*** ',A80)
1700 FORMAT(2I5,F10.3,A40)
1710 FORMAT(/21X,'*** WARNING : ONLY 2048 POINTS ARE USED IN THE',
     &              ' TIME DOMAIN COMPUTATION !!!')
1720 FORMAT(/21X,'*** WARNING : NP2 = 12 IS USED IN THE TIME DOMAIN',
     &              ' COMPUTATION INSTEAD OF ',I2,' !!!')
1730 FORMAT(/21X,'*** FREQUENCY RANGE USED IN COMPUTING MODULUS :',
     &       //25X,'NF = ',I5,'   ,   F1 = ',E15.7,' HERTZ  AND  ',
     &              'DF = ',E15.7,' HERTZ')
1740 FORMAT(//21X,'*** NORMALIZING FACTORS FOR OUTPUT TIME HISTORY :',
     &        //25X,'FACTA = ',F10.4,' G   ,   FACTV = ',F10.4,' CM/SEC',
     &              '   ,   FACTD = ',F10.4,' CM')
1750 FORMAT(//21X,'*** NO. OF ITERATIONS = ',I2,' : WITH  NIT1 = ',
     &              I2,'  &  NIT2 = ',I2)
1760 FORMAT(//21X,'*** DESIGN (TARGET) RESPONSE SPECTRUM :')
1770 FORMAT(//29X,'FREQ.',8X,'SA',/22X,'NO.',3X,'(HERTZ)',5X,'(G''S)',
     &          /22X,23('-'),/)
1780 FORMAT(//29X,'FREQ.',7X,'SV',/22X,'NO.',3X,'(HERTZ)',2X,'(CM/SEC)'
     &          ,/22X,23('-'),/)
1790 FORMAT(//29X,'*** OUTPUT FILE IS :  ',A80)
1800 FORMAT(//5X,'*** KEY6 = ',I1,' : OUTPUT FILES ARE :')
1820 FORMAT(/20X,I1,' :  ',A80)
1830 FORMAT(//20X,'*** FILTERING PARAMETERS FOR OUTPUT TIME HISTORY :',
     &        //25X,'FC1 = ',F10.4,' HZ   ,   NF1 = ',I5,
     &        //25X,'FC2 = ',F10.4,' HZ   ,   NF2 = ',I5)
1840 FORMAT(//5X,'*** COMPUTED OUTPUT PARAMETERS ***',
     &        //5X,'MEDIUM DAMPING, 1/2Q ..............  ',F10.3,' %',
     &        //5X,'SOURCE CORNER FREQUENCY ...........  ',F10.3,' HZ',
     &        //5X,'SOURCE RADIUS .....................  ',F10.3,' KM',
     &        //5X,'SOURCE-TO-SITE DISTANCE ...........  ',F10.3,' KM')
1860 FORMAT(//5X,'*** PEAK VALUES ***',//18X,'PEAK ACCELERATION',
     &              ' INFORMATION',14X,'PEAK VELOCITY INFORMATION',
     &       /10X,2(3X,37('-')),/6X,'ITER.',5X,'AMAX',6X,'ARMS',7X,
     &              'PFE',7X,'PFZ',6X,'VMAX',6X,'VRMS',7X,'PFE',7X,
     &              'PFZ',/7X,'NO.',2(5X,'(G''S)'),2(6X,'(HZ)'),2X,
     &             2(2X,'(CM/SEC)'),4X,'(HZ)',6X,'(HZ)',/6X,84('-'),/)
1880 FORMAT(5X,I4,1X,2(2F10.4,2F10.3))
1900 FORMAT(///5X,'!!! NOTE : * = FLAG FOR N VALUE < 2.0 !!!')
1920 FORMAT(I5,F5.3,5X,'ITERATION NO.  ',I2)
1940 FORMAT(/9X,'*** RVT SPECTRAL VALUES AT SPECTRAL DAMPING = ',F5.2,
     &             ' %  AND  AT ITERATION NO.  ',I2)
1950 FORMAT(/15X,'FREQ.',9X,'FAS',12X,'RSA',12X,'RSV',12X,'TSV',9X,
     &              'SPECTRAL',5X,'PERIOD')
1960 FORMAT(7X,'NO.',5X,'(HZ)',8X,'(G.SEC)',10X,'(G)',9X,'(CM/SEC)',
     &      10X,'(G)',11X,'RATIO',7X,'(SEC)',/7X,98('-'),/)
1970 FORMAT(7X,'NO.',5X,'(HZ)',8X,'(G.SEC)',10X,'(G)',9X,'(CM/SEC)',
     &       7X,'(CM/SEC)',9X,'RATIO',7X,'(SEC)',/7X,98('-'),/)
1980 FORMAT(7X,I3,F10.4,5E15.4,F10.4,5X,A1)
2000 FORMAT(6E15.7)
```

```
C
 2020 FORMAT(7X,98('-'),/7X,'MAX.  VALUES : ',5E15.4,//)
 2040 FORMAT(/9X,'*** SDF SPECTRAL VALUES AT SPECTRAL DAMPING = ',F5.2,
     &            ' %  AND  AT ITERATION NO.  ',I2)
 2050 FORMAT(/15X,'FREQ. ',9X,'FAS',12X,'PAA',12X,'PRV',12X,'TSV',9X,
     &            'SPECTRAL',5X,'PERIOD')
 2200 FORMAT(//5X,'*** OUTPUT TIME HISTORY INFORMATION ***')
 3000 FORMAT('OUTPUT ACCELERATION TIME HISTORY (G''S) : NIT = ',I2)
 3100 FORMAT(//9X,'*** ',A80,//13X,'NPT = ',I5,'  ,   DT = ',F10.4,
     &            ' SEC.  AND  AMAX = ',F10.4,' G')
 3200 FORMAT(I5,5X,'DT = ',F10.4,' SEC  ,  AMAX = ',F10.4,' G')
 3400 FORMAT(6E12.5)
 4000 FORMAT('OUTPUT VELOCITY TIME HISTORY (CM/SEC) : NIT = ',I2)
 4100 FORMAT(//9X,'*** ',A80,//13X,'NPT = ',I5,'  ,   DT = ',F10.4,
     &            ' SEC.  AND  VMAX = ',F10.4,' CM/SEC')
 4200 FORMAT(I5,5X,'DT = ',F10.4,' SEC  ,  VMAX = ',F10.4,' CM/SEC')
 5000 FORMAT('OUTPUT DISPLACEMENT TIME HISTORY (CM) : NIT = ',I2)
 5100 FORMAT(//9X,'*** ',A80,//13X,'NPT = ',I5,'  ,   DT = ',F10.4,
     &            ' SEC.  AND  DMAX = ',F10.4,' CM')
 5200 FORMAT(I5,5X,'DT = ',F10.4,' SEC  ,  DMAX = ',F10.4,' CM')
 9990 FORMAT(///5X,'***   E N D   O F   P R O G R A M   ***',////)
C
      END
```

FUNCTION BINOM(L, N)

```
      FUNCTION BINOM( L, N )
C
C     FUNCTION BINOM COMPUTES BINOMIAL COEFFICIENTS,
C     BINOM = N!/(L!(N-L)!).
C     NOTE : L MUST BE .LE. N
C
C
      BINOM = 1.0
C
      DO 10 I=2,N
      IF ( I .LE. L ) BINOM = BINOM / REAL(I)
      IF ( I .LE. (N-L) ) BINOM = BINOM / REAL(I)
      BINOM = BINOM * REAL(I)
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BRUNE( NFB, NFE, FREQ, FA )


      SUBROUTINE BRUNE( NFB, NFE, FREQ, FA )
C
C     SUBROUTINE BRUNE COMPUTES FOURIER AMPLITUDE, FA (G-SEC) BASED ON
C     THE METHOD SUGGESTED BY J. N. BRUNE (BSSA, COL. 75, SEPT. 1970).
C     RELATED PARAMETERS ARE CARRIED OVER FROM THE NAMED COMMON BLOCK,
C     FADATA FROM THE MAIN PROGRAM.
C
C
      DIMENSION  FREQ(*), FA(*)
C
      COMMON  /FADATA/ KEY1, KEY2, C, FC, PIR, Q, FQ, ALPHA, FMAX, N2,
     &                 CAP, PICAP
C
      COMMON  /PIDATA/ PI, PI2
C
      COMMON  /AMDATA/ AFREQ(100), AMFAC(100), NAMP
C
      COMMON  /SMDATA/ SV1, DAMP1, THICK, ARATIO, RD, RK, CK
C
C
      AMPF = 1.0
C
      DO 300 I=NFB,NFE
C
      RATIO = FC / FREQ(I)
C
C --- COMPUTES FREQUENCY DEPENDENT Q FUNCTION
C
      IF ( FQ .EQ. 0.0 .OR. ALPHA .EQ. 0.0 ) THEN
         QFUNCT = Q
      ELSE
         QFUNCT = Q * ( FREQ(I) / FQ ) ** ALPHA
      END IF
C
      ERATIO = PIR * FREQ(I) / QFUNCT
      FRATIO = 1.0 / ( 1.0 + RATIO * RATIO )
C
C --- INTERPOLATES FREQUENCY DEPENDENT AMPLIFICATION FACTOR, AMFAC AT
C     FREQUENCY, FREQ(I)
C
      IF ( KEY2 .EQ. 1 )  CALL INTERP(AFREQ, AMFAC, NAMP, FREQ(I), AMPF)
C
      FA (I) = C * EXP(-ERATIO) * FRATIO * AMPF
C
      IF ( FMAX .EQ. 0.0 .OR. N2 .EQ. 0 ) GO TO 100
C
C --- COMPUTES BUTTERWORTH FILTER
C
      FMFACT = SQRT( 1.0 + ( FREQ(I) / FMAX ) ** N2 )
      FA(I) = FA(I) / FMFACT
C
  100 IF ( CAP .EQ. 0.0 ) GO TO 200
C
C --- COMPUTES NEAR-SITE EXPONENTIAL FILTER
C
      FA(I) = FA(I) * EXP( -PICAP * FREQ(I) )
```

```
      SUBROUTINE BRUNE( NFB, NFE, FREQ, FA ).


C
  200 IF ( KEY1 .EQ. 0 ) GO TO 300
C
C --- COMPUTES SITE RESPONSE AT RECEIVER DEPTH, FAS IN THE OSCILLATOR
C     REGIME
C
      RK = PI2 * FREQ(I) / SV1
      CK = RK * DAMP1
C
      CALL SAMP( ARDTH )
C
      FA(I) = FA(I) * ARDTH
C
  300 CONTINUE
C
      RETURN
      END
```

SUBROUTINE BWORTH(F, FC, NP, HS)

```
      SUBROUTINE BWORTH( F, FC, NP, HS )
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C     BWORTH CALCULATES THE RESPONSE OF A NP POLE BUTTERWORTH FILTER
C     UP TO AS MANY POLES AS THE ARRAYS S AND T ARE DIMENSIONED
C
C     F  = FREQUENCY(HZ.)
C     FC = THE CORNER FREQUENCY OF THE FILTER
C     NP = THE NUMBER OF POLES, NEGATIVE FCR HIGH PASS
C     HS = COMPLEX RESPONSE OF THE FILTER
C
C
C     THE FORMULA USED -- H(S) = 1/(S-S1)*(S-S2) ... (S-SK)
C
C                     I*PI*(1/2+((2*K-1)/(2*NP)))
C     WHERE SK = EXP                                   K = 1,2, ... NP
C
C           S = I*(F/FC)
C
C     REF:  THEORY AND APPLICATION OF DIGITAL SIGNAL PROCESSING
C           RABINE & GOLD, PAGE 227, PRENTICE-HALL 1975
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      COMPLEX S(20), T(20), AS, BK, HS
C
      N=IABS(NP)
C
C
      HS=CMPLX(1.,0.)
      IF ( N .EQ. 0 ) GO TO 40
      IF ( F .EQ. 0. ) GO TO 40
      SS=ABS(F/FC)
      DO 10 K=1,N
      AN = K
      AK = 3.141592654 * (0.5 + (((2.*AN) -1.) / (2.*N)))
      BK = CMPLX(0.0,AK)
   10 S(K) = CEXP(BK)
C
      AS = CMPLX(0.0,SS)
      IF (NP .LT. 0) AS = 1./AS
      T(1) = AS - S(1)
      IF (N .EQ. 1) GO TO 30
      DO 20 I=2,N
   20 T(I) = (AS - S(I)) * T(I-1)
   30 CONTINUE
C
      HS = 1. / T(N)
   40 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE CMPMAX( KUQ, DT, UQ, PR, W, W2, W3, WD, D, Z )
```


```
      SUBROUTINE CMPMAX( KUQ, DT, UQ, PR, W, W2, W3, WD, D, Z )
```


```
C
C     SUBROUTINE CMPMAX COMPUTES RESPONSE SPECTRUM AT LOW FREQUENCY
C
C
      DIMENSION  UQ(*), Z(*), C(3), X(2,3)
C
      DO 10 I=1,3
      X(1,I)=0.
   10 Z(I)=0.
C
      F1 = 2.*D/(W3*DT)
      F2 = 1./W2
      F3 = D*W
      F4 = 1./WD
      F5 = F3*F4
      F6 = 2.*F3
       E = EXP(-F3*DT)
      Q1 = E*SIN(WD*DT)
      Q2 = E*COS(WD*DT)
      H1 = WD*Q2 - F3*Q1
      H2 = WD*Q1 + F3*Q2
C
      DO 100 K = 1, KUQ
      DUQ = UQ(K+1) - UQ(K)
      Z1 = F2*DUQ
      Z2 = F2*UQ(K)
      Z3 = F1*DUQ
      Z4 = Z1/DT
       B = X(1,1) + Z2 -Z3
       A = F4*X(1,2) + F5*B + F4*Z4
      X(2,1) = A*Q1 + B*Q2 + Z3 - Z2 - Z1
      X(2,2) = A*H1 - B*H2 - Z4
      X(2,3)=-F6*X(2,2)-W2*X(2,1)
C
      DO 80 L=1,3
      C(L)=ABS(X(2,L))
      IF (C(L) .LT. Z(L)) GO TO 80
      Z(L)=C(L)
   80 X(1,L)=X(2,L)
C
  100 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE COOL( N, X, SIGNI )


      SUBROUTINE COOL( N, X, SIGNI )
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C          COOL CALCULATES EITHER THE FORWARD OR INVERSE FINITE
C          FOURIER TRANSFORM OF A COMPLEX SERIES.
C
C                   NX
C          F(J) = SUM X(K)*EXP(I*SIGNI*2*PI*(K-1)*(J-1)/NX)  J=1,NX
C                   K=1
C
C          WHERE NX MUST BE AN EXACT POWER OF 2.
C
C          INPUT...
C            N          LOG(NX) TO THE BASE 2
C            X          COMPLEX VECTOR OF DIMENSION .GE. NX
C            SIGNI      .EQ. -1.0 FOR COMPUTATION OF FORWARD TRANSFORM
C                                 (FROM TIME DOMAIN TO FREQUENCY DOMAIN)
C                       .EQ. +1.0 FOR COMPUTATION OF INVERSE TRANSFORM
C                                 (FROM FREQUENCY DOMAIN TO TIME DOMAIN)
C
C          OUTPUT...
C            X          THE TRANSFORM IS STORED IN THE POSITION OF THE
C                       ORIGINAL SERIES. THE REAL PART CONTAINS THE
C                       COSINE SERIES AND IS SYMMETRIC ABOUT THE POINT
C                       2**(N-1)+1.  THE IMAGINARY PART CONTAINS THE SINE
C                       SERIES AND IS ASYMMETRIC ABOUT THE POINT
C                       2**(N-1)+1.  POINT 1 IS FOR ZERO FREQUENCY AND
C                       POINT 2**(N-1)+1 IS FOR THE NYQUIST FREQUENCY.
C
C          NOTE...
C            THE COMPLEX FACTOR 1/NX = 1/2**N IS NOT APPLIED.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      COMPLEX X(*), CARG, CEXP, CW, CTEMP, CPI
C
      CPI = CMPLX(0.0,3.1415965358979*SIGNI)
      LX  = 2**N
      J   = 1
C
      DO 30 I=1,LX
      IF (I .GT. J) GO TO 10
      CTEMP = X(J)
      X(J) = X(I)
      X(I) = CTEMP
   10 M = LX / 2
C
   20 IF (J .LE. M) GO TO 30
      J = J - M
      M = M / 2
      IF (M .GE. 1) GO TO 20
C
   30 J = J + M
      L = 1
C
```

```
      SUBROUTINE COOL( N, X, SIGNI )


   40 ISTEP = L + L
      DO 50 M=1,L
      CARG = CPI * (M-1) / L
      CW = CEXP(CARG)
C
      DO 50 I=M,LX,ISTEP
      CTEMP = CW * X(I+L)
      X(I+L) = X(I) - CTEMP
   50 X(I) = X(I) + CTEMP
C
      L = ISTEP
      IF (L .LT. LX) GO TO 40
C
      RETURN
      END
```

SUBROUTINE INTERB (X,Y,N,XX,YY)

```
      SUBROUTINE INTERB (X,Y,N,XX,YY)
C
C     SUBROUTINE INTERB LINEARLY INTERPOLATES ANY POINTS BETWEEN TWO
C     SPECIFIED POINTS.  IT INTERPOLATES YY AT XX WITHIN N PAIRS OF
C     (X, Y) POINTS.  IF XX < X(1), YY IS SET TO EQUAL TO 1.0, AND
C     IF XX > X(N), YY IS SET TO EQUAL TO 1.0.
C
      DIMENSION X(*),Y(*)
      IF (XX .GT. X(1)) GO TO 10
      YY = 1.0
      RETURN
C
   10 IF (XX .LT. X(N)) GO TO 20
      YY = 1.0
      RETURN
C
   20 DO 30 I=2,N
      IF (XX .LT. X(I)) GO TO 40
   30 CONTINUE
   40 YY = Y(I-1)+(Y(I)-Y(I-1))*(XX-X(I-1))/(X(I)-X(I-1))
C
      RETURN
      END
```

SUBROUTINE INTERP (X,Y,N,XX,YY)

```
      SUBROUTINE INTERP (X,Y,N,XX,YY)
C
C     SUBROUTINE INTERP LINEARLY INTERPOLATES ANY POINTS BETWEEN TWO
C     SPECIFIED POINTS. IT INTERPOLATES YY AT XX WITHIN N PAIRS OF
C     (X, Y) POINTS. IF XX < X(1), YY IS SET TO EQUAL TO Y(1), AND
C     IF XX > X(N), YY IS SET TO EQUAL TO Y(N).
C
      DIMENSION X(*),Y(*)
      IF (XX .GT. X(1)) GO TO 10
      YY = Y(1)
      RETURN
C
   10 IF (XX .LT. X(N)) GO TO 20
      YY = Y(N)
      RETURN
C
   20 DO 30 I=2,N
      IF (XX .LT. X(I)) GO TO 40
   30 CONTINUE
   40 YY = Y(I-1)+(Y(I)-Y(I-1))*(XX-X(I-1))/(X(I)-X(I-1))
C
      RETURN
      END
```

SUBROUTINE SAMP(ARDTH)

```
      SUBROUTINE SAMP( ARDTH )
C
C     SUBROUTINE SAMP COMPUTES SITE AMPLIFICATION AT RECEIVER DEPTH.
C
C
      COMMON  /SMDATA/ SV1, DAMP1, THICK, ARATIO, RD, RK, CK
C
C
      COMPLEX  CARD, CATH, ATH
C
      RKRD = RK * RD
      CKRD = CK * RD
C
      RKTH = RK * THICK
      CKTH = CK * THICK
C
      CARD = CMPLX( RKRD, CKRD )
      CATH = CMPLX( RKTH, CKTH )
C
      ARD = CABS(CCOS(CARD))
      ATH = CCOS(CATH) - CMPLX( 0.0, 1.0 ) * ARATIO * CSIN(CATH)
      ARDTH = ARD / CABS(ATH)
C
      RETURN
      END
```

SUBROUTINE SIMPS(N, DELTA, FUNX, AREA)

```
      SUBROUTINE SIMPS( N, DELTA, FUNX, AREA )
C
C     SUBROUTINE SIMPS INTEGRATES INPUT FUNCTION BY SIMPSON'S RULE,
C     NOTE : N MUST BE AN EVEN NO., & FUNX(I) MUST HAVE (N+1) TERMS.
C
      DIMENSION  FUNX(*)
C
C
      SUM = FUNX(1)
C
      DO 10 I=2,N,2
   10 SUM = SUM + 4.0 * FUNX(I) + 2.0 * FUNX(I+1)
      SUM = SUM - FUNX(N+1)
C
      AREA = DELTA * SUM / 3.0
C
      RETURN
      END
```

```
      SUBROUTINE SPECT( NPT, DT, A, PAA, PRV )
```



```
      SUBROUTINE SPECT( NPT, DT, A, PAA, PRV )
```



```
C
C     SUBROUTINE SPECT COMPUTES A RESPONSE SPECTRUM OF A SINGLE-DEGREE-
C     OF-FREEDOM SYSTEM IN THE TIME DOMAIN BY SOLVING A SET OF LINEAR
C     SIMULTANEOUS EQUATIONS WITH RECURSION RELATIONSHIPS.
C
C
      DIMENSION  A(*), PAA(*), PRV(*), Z(3)
C
      COMMON /SPDATA/ DAMP, NFREQ, WI(145), PER(145)
C
C
      KUG = NPT - 1
      TTEST = 10.0 * DT
      YY = SQRT( 1.0 - DAMP * DAMP )
C
      DO 20 I=3,NFREQ
      PR = PER(I)
      W1 = WI(I)
      W2 = W1 * W1
      W3 = W1 * W2
      WD = W1 * YY
C
      IF ( PR .LT. TTEST ) THEN
C
         CALL UCMPMX( KUG, DT, A, PR, W1, W2, W3, WD, DAMP, Z )
C
      ELSE
C
         CALL CMPMAX( KUG, DT, A, PR, W1, W2, W3, WD, DAMP, Z )
C
      END IF
C
      PRV(I) = W1 * Z(1) * 981.0
      PAA(I) = W2 * Z(1)
C
   20 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE TIME( IFLAG, FC1, NF1, FC2, NF2, CP, SP, OTH, OTHMX )


      SUBROUTINE TIME( IFLAG, FC1, NF1, FC2, NF2, CP, SP, OTH, OTHMX )
C
C     SUBROUTINE TIME COMPUTES THE FFT OF AN INPUT ACCELERATION TIME
C     HISTORY AND EXTRACTS THE PHASE.  IT ALSO COMBINES AN INPUT MODULUS
C     (BRUNE FOURIER AMPLITUDE) WITH THE PHASE AND COMPUTES AN OUTPUT
C     TIME HISTORY (ACCELERATION, VELOCITY OR DISPLACEMENT).
C
C     THIS SUBROUTINE CALLS A SUBROUTINE, COOL (AN FFT ALGARITHM) TO DO
C     THE TRANSFORMATION, AND CALLS A SUBROUTINE, BWORTH (A BUTTERWORTH
C     FILTERING ALGARITHM) TO DO THE FILTERING FOR COMPUTING OUTPUT
C     TIME HISTORIES.
C
C
      DIMENSION  CP(*), SP(*), OTH(*)
C
      COMMON  /PIDATA/ PI, PI2
C
      COMMON  /TMDATA/ NPIA, NPT, NPT2, NP2, NPFR, DT,
     &                 A(4100), PFREQ(2050), PFAS(2050)
C
      COMPLEX  XX(4100), RR, HS
C
C
      IF ( IFLAG .GE. 0 ) GO TO 500
C
C --- COMPUTES THE MEAN OF THE INPUT ACCELERATION TIME HISTORY
C
      SUM = 0.0
      DO 120 I=1,NPIA
  120 SUM = SUM + A(I)
      AMEAN = SUM / FLOAT( NPIA )
C
C --- REMOVES THE MEAN FROM THE INPUT ACCELERATION TIME HISTORY
C
      DO 140 I=1,NPIA
  140 A(I) = A(I) - AMEAN
C
C --- ASSUMES 5 % OF NPIA FROM THE INPUT ACCELERATION TIME HISTORY FOR
C     COMPUTING THE COSINE TAPER AT BOTH ENDS OF THE TIME HISTORY
C
      NCT1 = NINT( 0.05 * FLOAT( NPIA ) )
      NCT2 = NPIA - NCT1 + 1
      CTFAC = PI / FLOAT( NCT1 )
C
C --- COMPUTES COSINE TAPER AT THE FIRST AND LAST NCT1 POINTS FOR THE
C     INPUT ACCELERATION TIME HISTORY
C
      DO 200 I=1,NCT1
  200 A(I) = A(I) * ( 0.5 - 0.5 * COS( CTFAC * FLOAT(I) ) )
C
      DO 220 I=NCT2, NPIA
  220 A(I) = A(I) * ( 0.5 - 0.5 * COS( CTFAC * FLOAT(I) ) )
C
C --- ADDS TRAILING ZEROS TO THE CONDITIONED INPUT ACCELERATION TIME
C     HISTORY
C
```

```
      SUBROUTINE TIME( IFLAG, FC1, NF1, FC2, NF2, CP, SP, OTH, OTHMX )


      DO 300 I=NPIA+1, NPT
  300 A(I) = 0.0
C
C --- ENTERS FFT CALCULATION

C --- TRANSFORMS THE INPUT ACCELERATION TIME HISTORY TO THE FREQUENCY
C     DOMAIN
C
      DO 400 I=1,NPT
  400 XX(I) = CMPLX( A(I), 0.0 )
C
      CALL COOL( NP2, XX, -1.0 )
C
C --- COMPUTES THE COSINE AND SINE OF PHASE
C
      DO 420 I=1,NPFR
      RB = CABS( XX(I) ) * DT
      CP(I) = REAL( XX(I) ) / RB
      SP(I) = AIMAG( XX(I) ) / RB
  420 CONTINUE
C
      RETURN
C
C --- INITIALIZES A DUMMY NORMALIZING COMPLEX VARIABLE, HS, AND RR
C
C --- ENTERS INVERSE FFT CALCULATION
C
  500 RR = CMPLX( 1.0, 0.0 )
      HS = RR
C
C --- XX(I) IS THE COMPLEX FOURIER SPECTRUM ARRAY
C --  XX(1) IS ZERO FREQUENCY ELEMENT ( SET TO ZERO, MEAN = 0.0 )
C
      XX(1) = CMPLX( 0.0, 0.0 )
C
C --- ADDS PHASE ( CP, SP ) OF THE CONDITIONED INPUT ACCELERATION TIME
C     HISTORY TO SCALE THE BRUNE MODULUS, PFAS
C
      DO 600 I=2,NPFR
C
      XX(I) = PFAS(I-1) * CMPLX( CP(I), SP(I) )
C
C --- COMPUTES THE FIRST BUTTERWORTH FILTER
C
      CALL BWORTH( PFREQ(I-1), FC1, NF1, HS )
      IF ( FC1 .LT. 0.0 ) HS = 1.0 / HS
      RR = RR * HS
C
C --- COMPUTES THE SECOND BUTTERWORTH FILTER
C
      CALL BWORTH( PFREQ(I-1), FC2, NF2, HS )
      IF ( FC2 .LT. 0.0 ) HS = 1.0 / HS
      RR = RR * HS
C
      XX(I) = XX(I) * RR
C
```

```
      SUBROUTINE TIME( IFLAG, FC1, NF1, FC2, NF2, CP, SP, OTH, OTHMX )


      RR = CMPLX( 1.0, 0.0 )
      HS = RR
      PWI = PI2 * PFREQ(I-1)
      IF ( IFLAG .GE. 1 ) HS = ( CMPLX( 0.0, -PWI ) ) ** IFLAG
C
C --- DIVIDES THE SCALED SPECTRUM BY COMPLEX OMEGA ** IFALG :
C     IFLAG = 0 : COMPUTES OUTPUT ACCELERATION TIME HISTORY
C     IFLAG = 1 : COMPUTES OUTPUT VELOCITY TIME HISTORY
C     IFLAG = 2 : COMPUTES OUTPUT DISPLACEMENT TIME HISTORY
C
      XX(I) = XX(I) / ( HS * FLOAT(NPT) * DT )
C
C --- NPT * DT IS THE NORMALIZING FACTOR FOR FFT SUBROUTINE COOL.
C     INPUT ACCELERATION TIME HISTORY OF DELTA FUNCTION OF 1/DT
C     YIELDS SPECTRAL DENSITY OF UNITY.
C
      J = NPT2 - I
      XX(J) = CONJG( XX(I) )
C
      HS = CMPLX( 1.0, 0.0 )
C
  600 CONTINUE
C
C --- COMPUTES THE INVERSE FFT
C
      XX(NPFR) = CMPLX( REAL( XX(NPFR) ), 0.0 )
C
      CALL COOL( NP2, XX, 1.0 )
C
      OTHMX = OTH(1)
      DO 700 I=1,NPT
      OTH(I) = REAL( XX(I) )
      IF ( OTHMX .LE. ABS(OTH(I)) ) OTHMX = ABS(OTH(I))
  700 CONTINUE
C
      RETURN
      END
```

SUBROUTINE UCMPMX(KUQ, DT, UQ, PR, W, W2, W3, WD, D, Z)

```
      SUBROUTINE UCMPMX( KUQ, DT, UQ, PR, W, W2, W3, WD, D, Z )
C
C     SUBROUTINE UCMPMX COMPUTES RESPONSE SPECTRUM AT HIGH FREQUENCY
C
C
      DIMENSION  UQ(*), Z(*), C(3), X(2,3)
C
      DO 10 I=1,3
      X(1,I)=0.
   10 Z(I)=0.
C
      F2=1./W2
      F3=D*W
      F4=1./WD
      F5=F3*F4
      F6=2.*F3
C
      DO 100 K=1,KUQ
      NS=INT(10.*DT/PR-0.01)+1
      DDT=DT/FLOAT(NS)
      F1=2.*D/W3/DDT
      E=EXP(-F3*DDT)
      G1=E*SIN(WD*DDT)
      G2=E*COS(WD*DDT)
      H1=WD*G2-F3*G1
      H2=WD*G1+F3*G2
      DUG=(UQ(K+1)-UQ(K))/FLOAT(NS)
      G=UQ(K)
      Z1=F2*DUG
      Z3=F1*DUG
      Z4=Z1/DDT
C
      DO 100 IS=1,NS
      Z2=F2*G
      B=X(1,1)+Z2-Z3
      A=F4*X(1,2)+F5*B+F4*Z4
      X(2,1)=A*G1+B*G2+Z3-Z2-Z1
      X(2,2)=A*H1-B*H2-Z4
      X(2,3)=-F6*X(2,2)-W2*X(2,1)
C
      DO 80 L=1,3
      C(L)=ABS(X(2,L))
      IF (C(L) .LT. Z(L)) GO TO 80
      Z(L)=C(L)
   80 X(1,L)=X(2,L)
C
      G=G+DUG
C
  100 CONTINUE
C
      RETURN
      END
```

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Table 1

Source and Propagation Parameters

	Western United States (WUS)	Eastern United States (EUS)
ρ (cgs)	2.7	2.5
β (km/sec)	3.2	3.5
f_{max}	15.0	40.0
k(kappa)	0.0	0.0
Q(f)	300.0*	500.0 $(f)^{0.65}$
$\Delta\sigma$ (bars)	50.0	100.0
M_o(cgs)	$\log M_o = 1.5\ M_w + 16.1$	$\log M_o = 1.8\ M_b + 14.1$
Z(f) amplification factors	See Table 2	1.0
G(R)**	R^{-1}	R^{-1}
T***	f_c^{-1}	f_c^{-1}
f_c	$\Delta\sigma\ \beta^3 /\ 8.44\ M_o$	$\Delta\sigma\ \beta^3 / 8.44\ M_o$

*since there are several proposed frequency dependencies, Q was left constant for these predictions

**geometrical attenuation

***source duration

Table 2

Near surface amplification factors (from Boore, 1985)

log f	$\log \sqrt{\dfrac{\beta_0 \rho_0}{\beta_R \rho_R}}$ *
-1.0	0.01
-0.5	0.04
0.0	0.13
0.5	0.34
1.0	0.37

*ρ_0 and ρ_R are assumed to be equal

f = frequency

0,R refers to average crustal properties and near receiver properties respectively.

Table 3

Single Layer Site Parameters

Thickness (m)	β (km/sec)	ρ (cgs)	ζ (%) (damping)
40	0.3	2.1	5
	0.6	2.4	0

TABLE 4

*** M4. NF. DATA

BUILT-IN ACCELERATION TIME HISTORY FOR M < 4.5, R < 30 KM. : M4. NF DATA
OROVILLE AFTERSHOCK, CALIF., 8/16/75, ML = 4.0, R = 10.5 KM : CDMG STA P08SOOE
1320 PTS., DT = 0.010 SEC., AMAX = 0.068 G

*** M4. FF. DATA

BUILT-IN ACCELERATION TIME HISTORY FOR M < 4.5, R > 30 KM. : M4. FF. DATA
OROVILLE AFTERSHOCK, CALIF., 8/16/75, ML = 4.0, R = 10.5 KM : CDMG STA. P08SOOE
1320 PTS., DT = 0.010 SEC., AMAX = 0.068 G

*** M5. NF. DATA

BUILT-IN ACCELERATION TIME HISTORY FOR 4.5 < M < 5.5, R < 30 KM. : M5 NF DATA
OROVILLE AFTERSHOCK, CALIF., 8/6/75, ML = 4.9, R = 8.6 KM : CDMG STA. K06N35E
1364 PTS., DT = 0.010 SEC., AMAX = 0.105 G

*** M5. FF DATA

BUILT-IN ACCELERATION TIME HISTORY FOR 4.5 < M < 5.5, R > 30 KM : M5 FF DATA
COYOTE LAKE EQ., CALIF., 8/6/79, ML = 5.9, R = 29.4 KM : USGS STA. CL10S57E
2847 PTS., DT = 0.010 SEC., AMAX = 0.106 G

*** M6. NF. DATA

BUILT-IN ACCELERATION TIME HISTORY FOR 5.5 < M < 6.5, R < 30 KM. : M6 NF DATA
COYOTE LAKE EQ., CALIF., 8/6/79, ML = 5.9, R = 18.4 KM : USGS STA. CL02S40E
2683 PTS., DT = 0.010 SEC., AMAX = 0.110 G

*** M6. FF. DATA

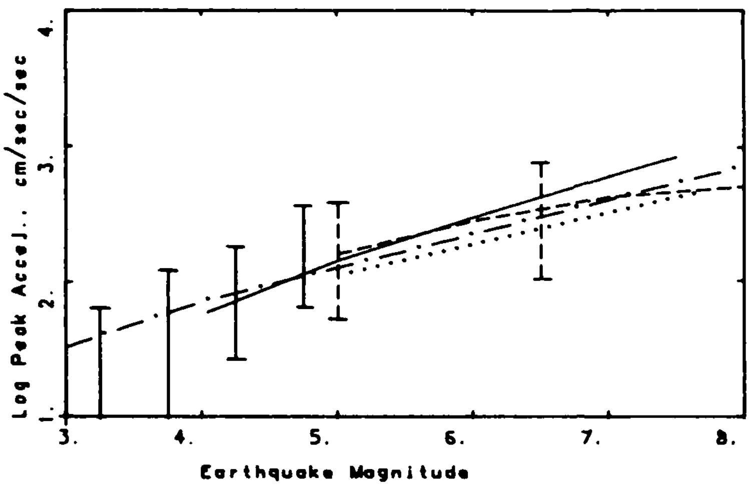
BUILT-IN ACCELERATION TIME HISTORY FOR 5.5 < M < 6.5, R > 30 KM. : M6 FF DATA
COYOTE LAKE EQ., CALIF., 8/6/79, ML = 5.9, R = 29.4 KM : USGS STA. CL10S57E
2847 PTS., DT = 0.010 SEC., AMAX = 0.106 G

*** M7. NF. DATA

BUILT-IN ACCELERATION TIME HISTORY FOR M > 6.5, R < 30 KM. : M7. NF. DATA
SAN FERNANDO EQ., CALIF., 2/9/71, ML = 6.4, R = 24.5 KM : USGS STA. J144N69W
2500 PTS., DT = 0.010 SEC., AMAX = 0.283 G

*** M7. FF. DATA

BUILT-IN ACCELERATION TIME HISTORY FOR M > 6.5, R > 30 KM. : M7. NF. DATA
IMPERIAL VALLEY, CALIF., 10/15/79, ML = 6.6, R > 40.0 KM : USGS STA IV25N45E
2833 PTS., DT = 0.010 SEC., AMAX = 0.110 G



WES : ATTENUATION (Log Ap)
MAGNITUDE SCALING (R < 15 km)

LEGEND

- ——— Western US (R = 10 km)
- ····· Joyner & Boore. 1982 (R = 10 km)
- – – – – Seed & Idriss. Rock. 1982 (R = 10 km)
- — · — Donovan. 1973 (R = 10 km)
- Seekins & Hanks. 1978 (0 < R < 10 km)
- Joyner & Boore. 1981 (0 < R < 15 km)

Figure 1. WUS Magnitude scaling at close distances for several attenuation relations. Each relation is calculated at a distance of 10 km however the distance definitions differ. Seed and Schnabel (1982) and Donovan (1973) employ a closest distance, Joyner and Boore (1982) use closet distance to the causative fault, while the Brune definition is for hypocentral range. The data ranges (shown by vertical bars) are for hypocentral distances of less than 15 km. See Table 1 for WUS parameters

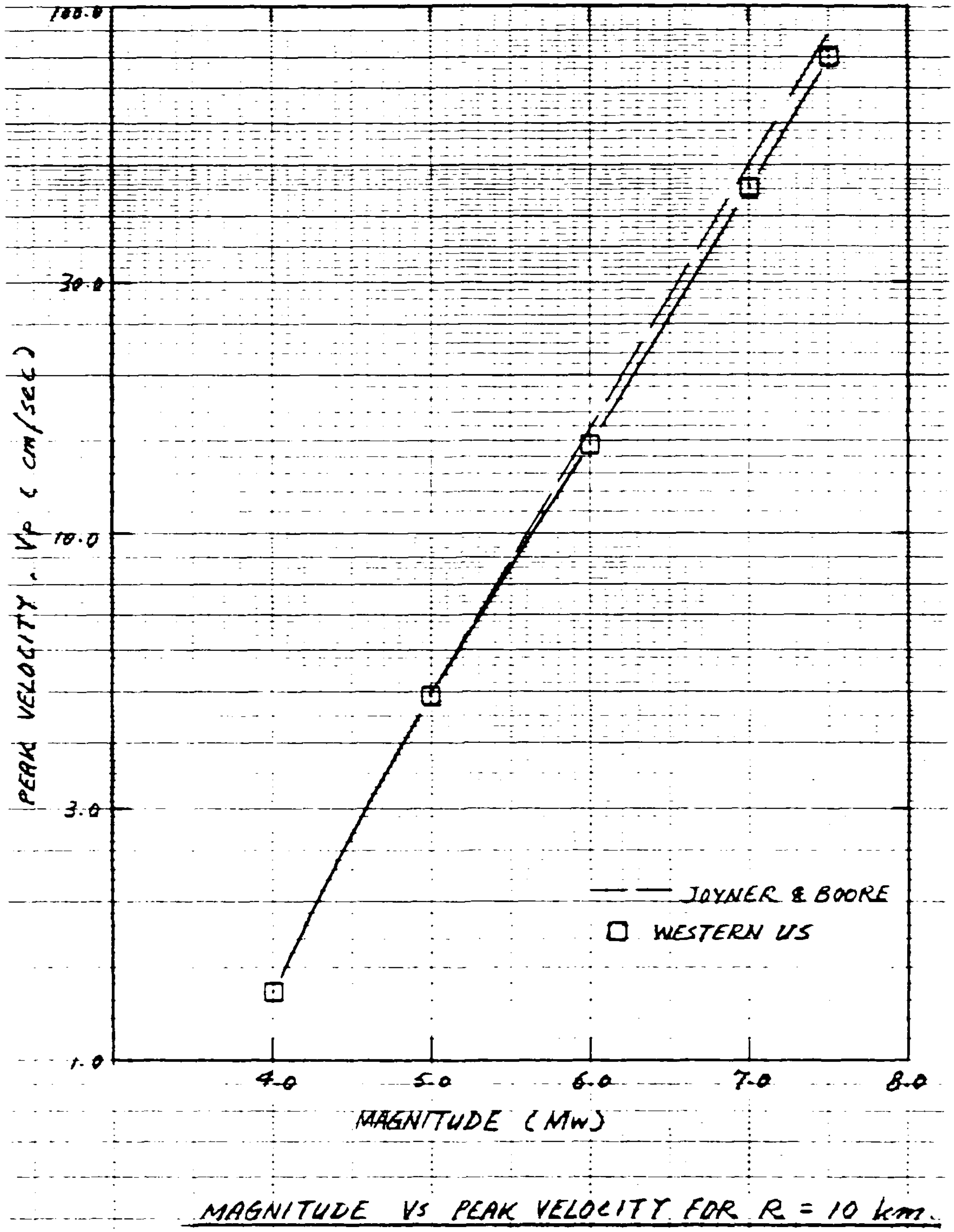


Figure 2. Peak particle velocity at a distance of 10 km vs moment magnitude (M_W) for the RVT model compared to the prediction of Joyner-Boore (1982) for WUS.

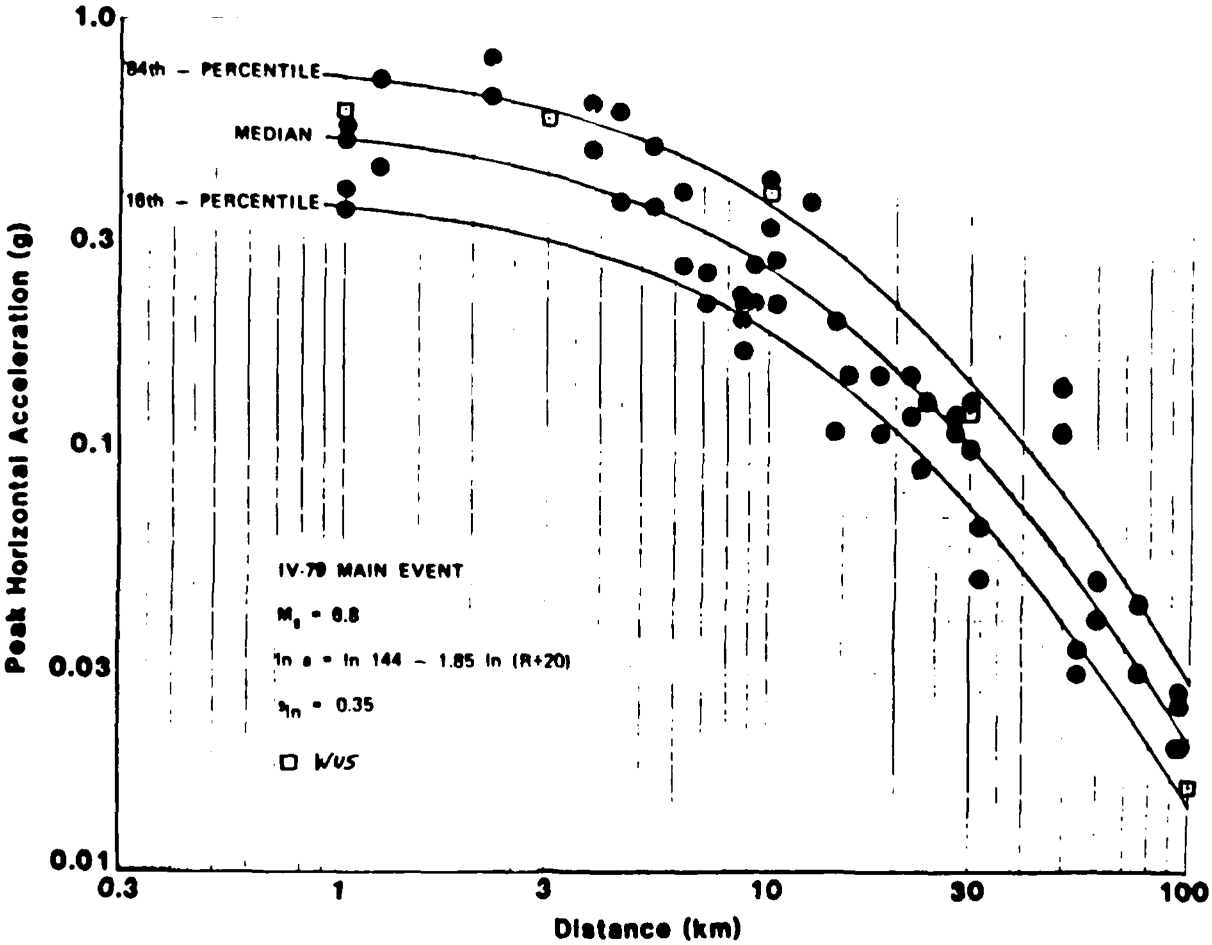


Figure 3. WUS distance scaling for the RVT model (open symbols) for M_W 7 and a source depth of 10 km. Data from the 1979 Imperial Valley main shock. Median and $\pm$ 1σ curves are from regression analyses Idriss, 1983)

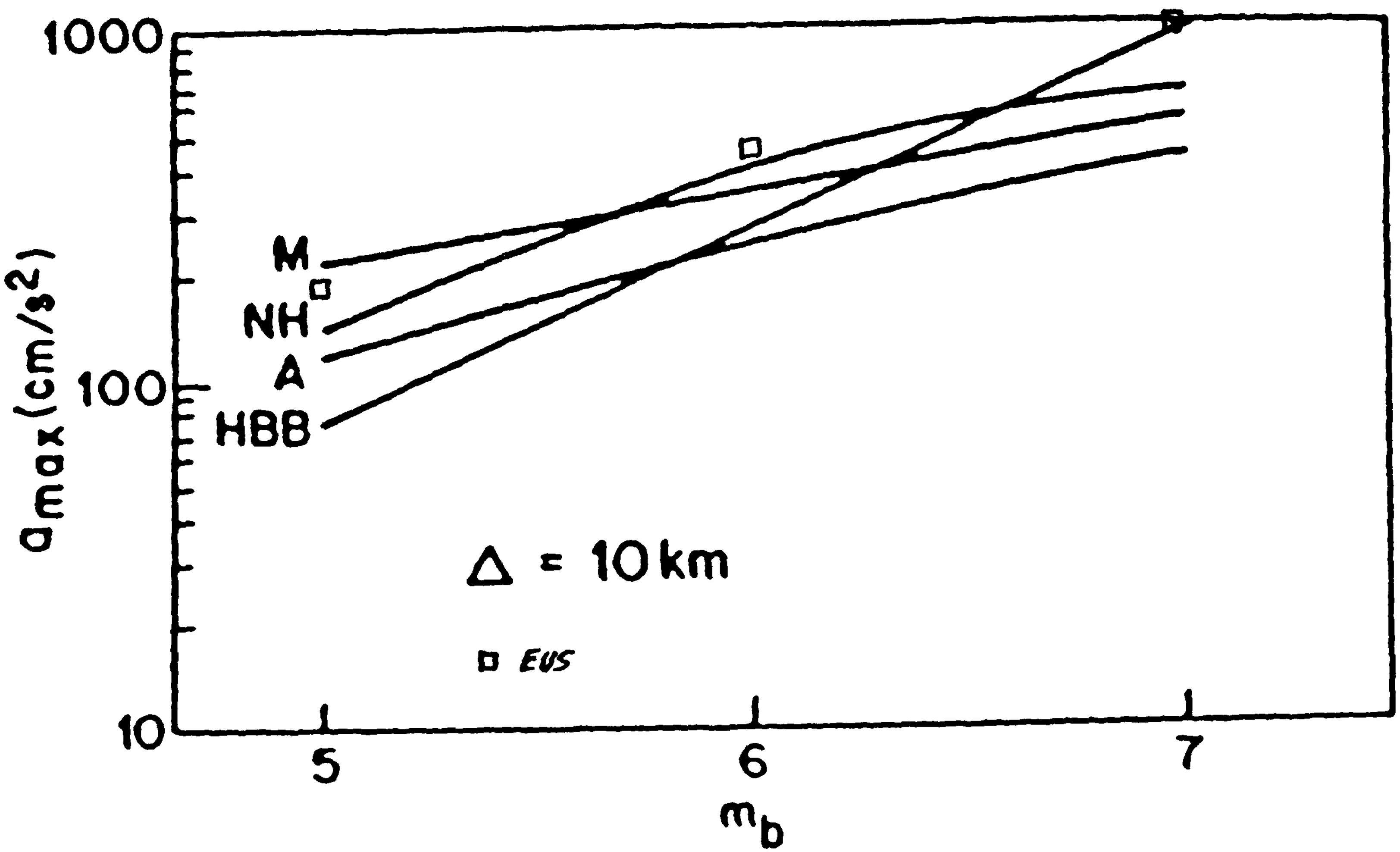


Figure 4. EUS magnitude scaling (m_b) for several attenuation relations: HBB, Hasegawa et al. (1981); M, McGuire (1984); NH, Nuttli and Herrmann (1984). Figure taken from Atkinson (1984). Open symbols are from the RVT model with EUS parameters (Table 1)

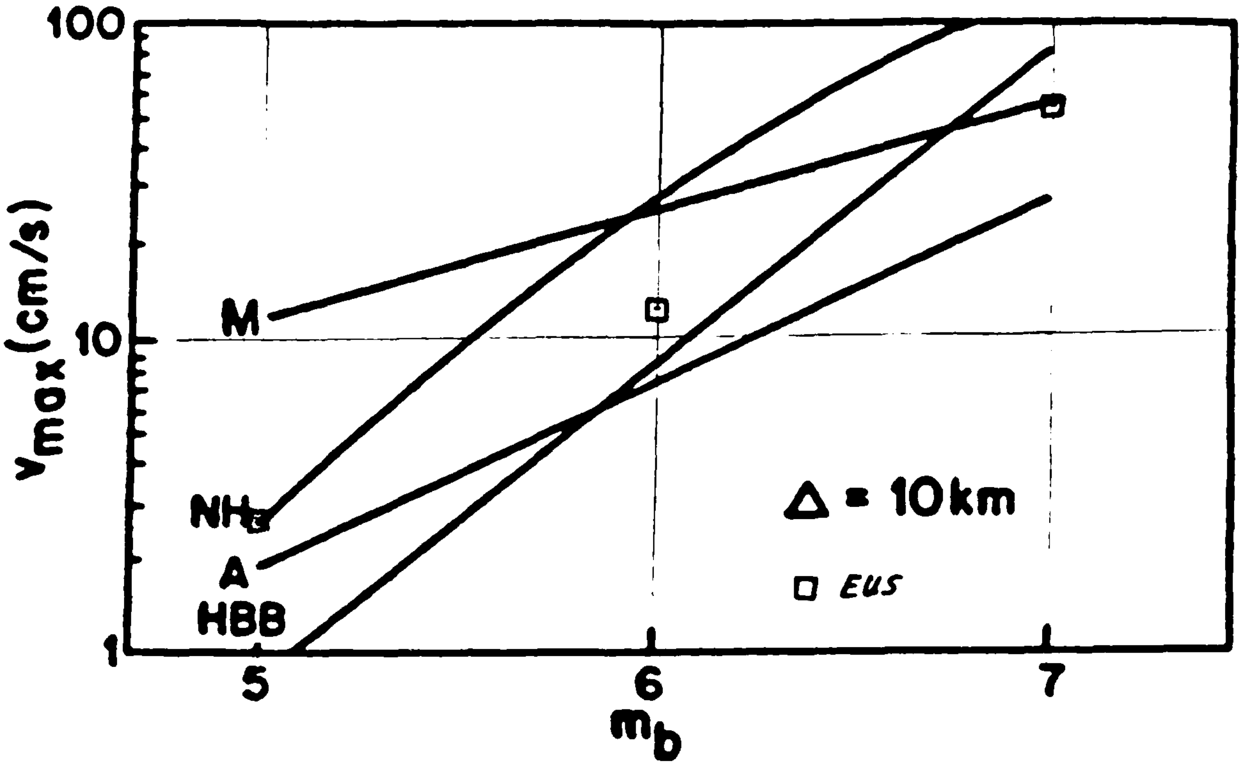
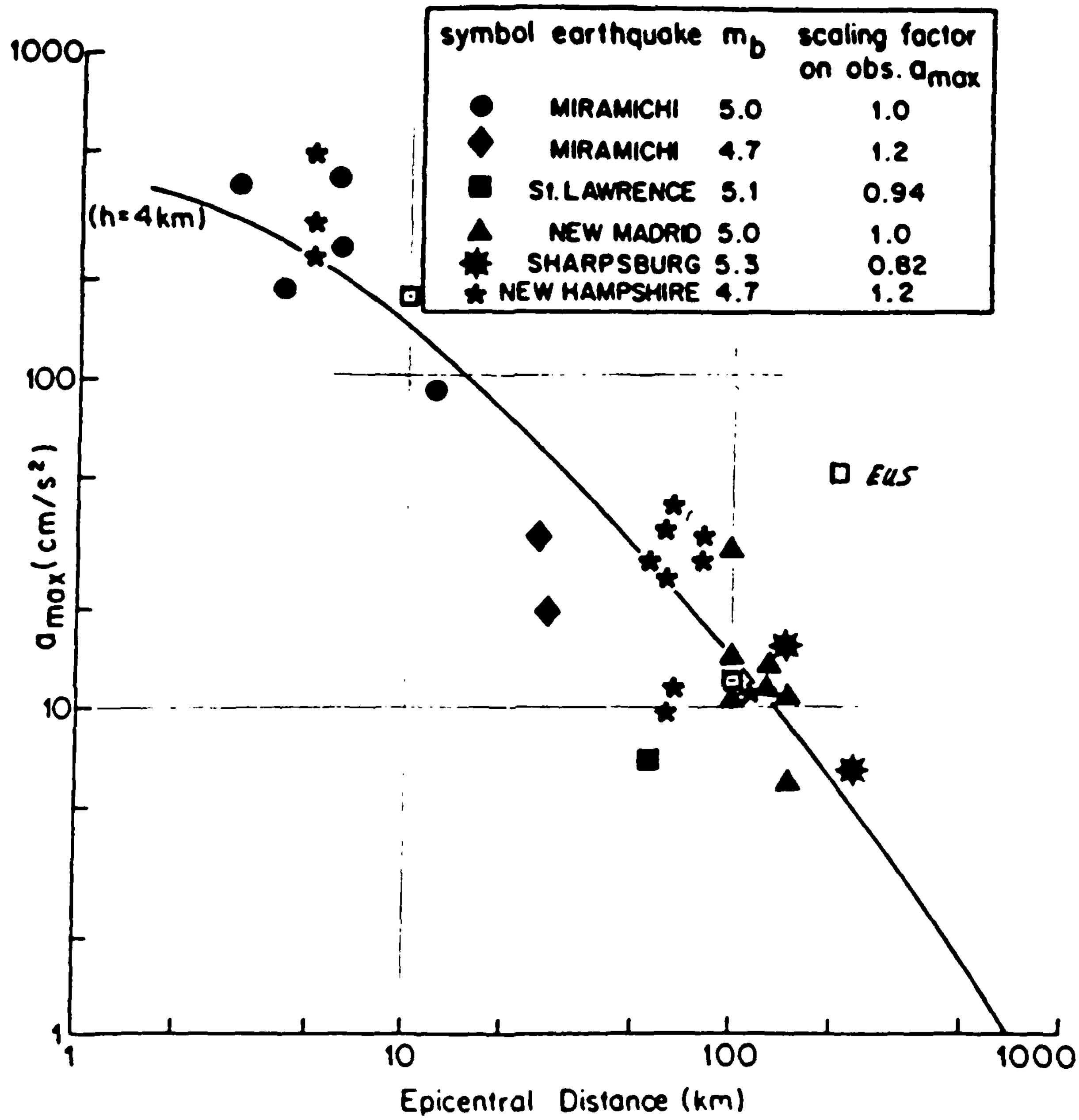


Figure 5. Peak particle velocity at a distance of 10 km vs magnitude (m_b) for several EUS attenuation relations: HBB, Hasegaaw et al. (1981); M, McGuire (1984); A, Atkinson (1984). Figure taken from Atkinson (1984). Open symbols are from the RVT model with EUS parameters (Table 1)



PEAK GROUND ACCELERATION

Figure 6. EUS peak acceleration distance scaling for the RVT model (open symbols) for m_b = 5 and a source depth of 4 km. Figure taken from Atkinson (1984) with data as indicated. Solid line is Atkinson's (1984) Eastern Canada attenuation relation for m_b = 5

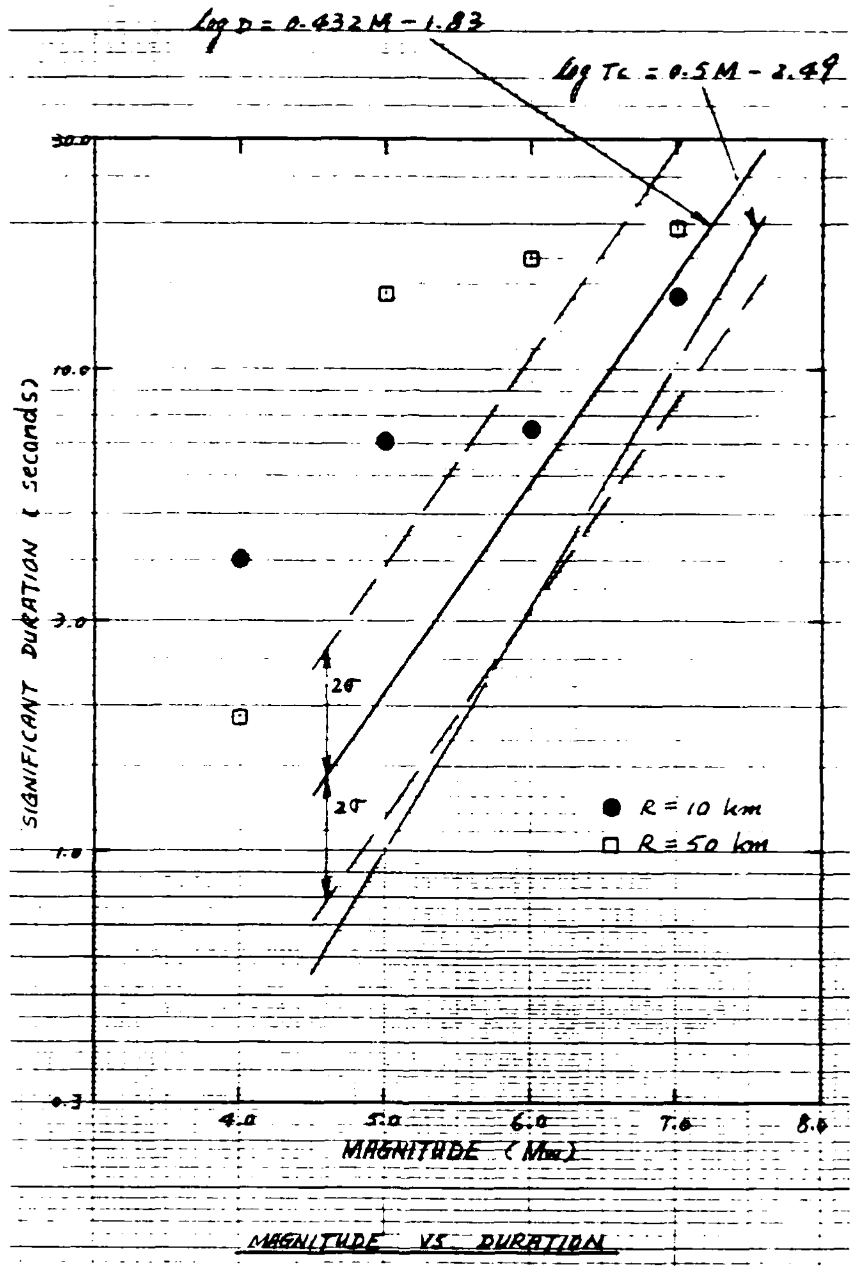
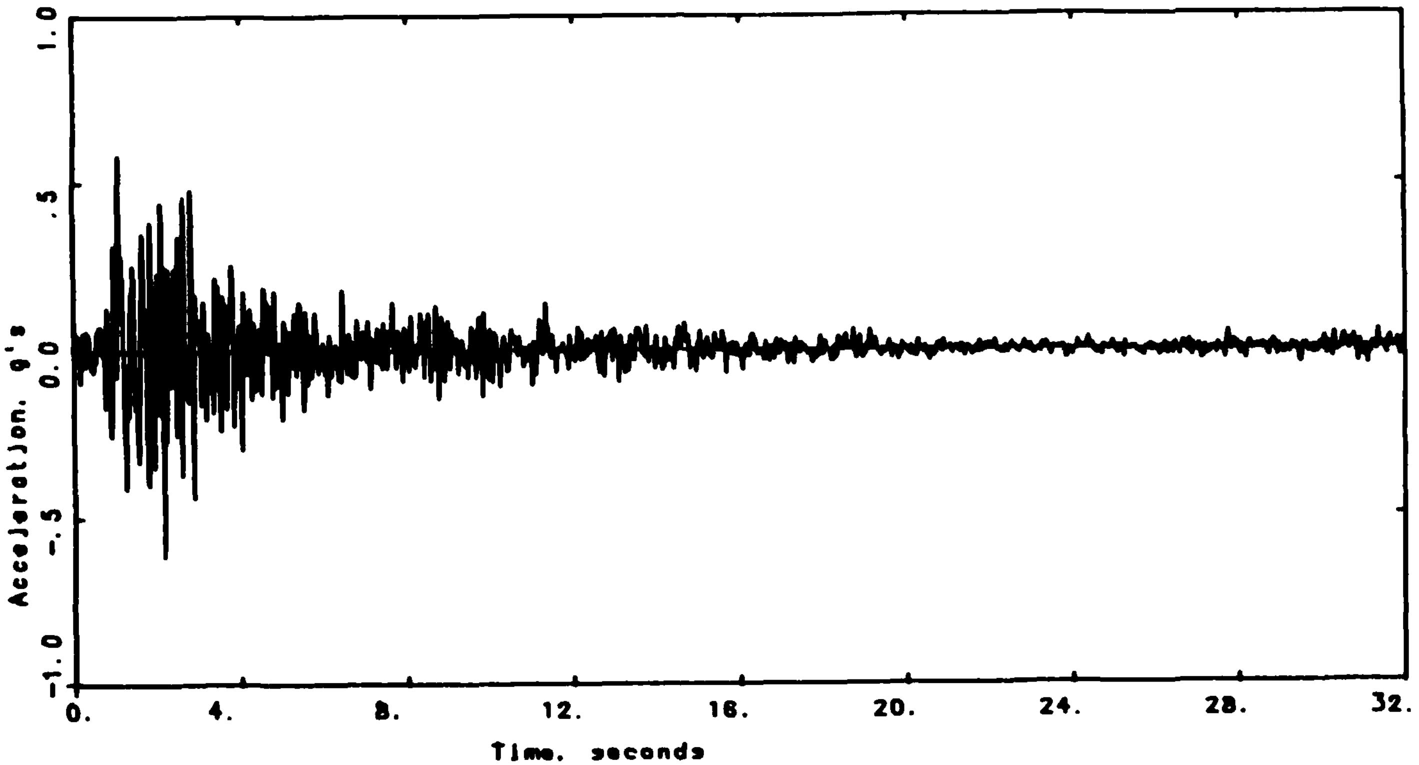


Figure 7. Plot of significant duration (5% to 95% Arias intensity, Dobry et al., 1978) for the synthetic time time histories. WUS scaling is used (Table 1) and the Brune modulus is calculated for R = 10 and R = 50 km. Based upon the magnitude and distance selection criterion (see Section 6.0) appropriate time histories are automatically selected and their phases combined with the Brune modulus. Also shown is the empirical curve from Dobry et al., (1978) with the $\pm 2\sigma$ lines. Interestingly enough, the inverse corner frequency relations (log T_C = 0.5 M - 2.49, from Table 1) is nearly within the $\pm 2\sigma$ line

Figure Set 8. Plots of synthesized acceleration, velocity, and displacement time histories for WUS and EUS tectonic environments. The event has a magnitude of 7 (M_W for WUS, m_b for EUS) at a hypocentral range of 10 km. The phase was extracted from a recording of the 1971 San Fernando (M_L = 6.4) at a hypocentral range of 24.5 km. Plots of response spectra are also shown following the displacement time histories.

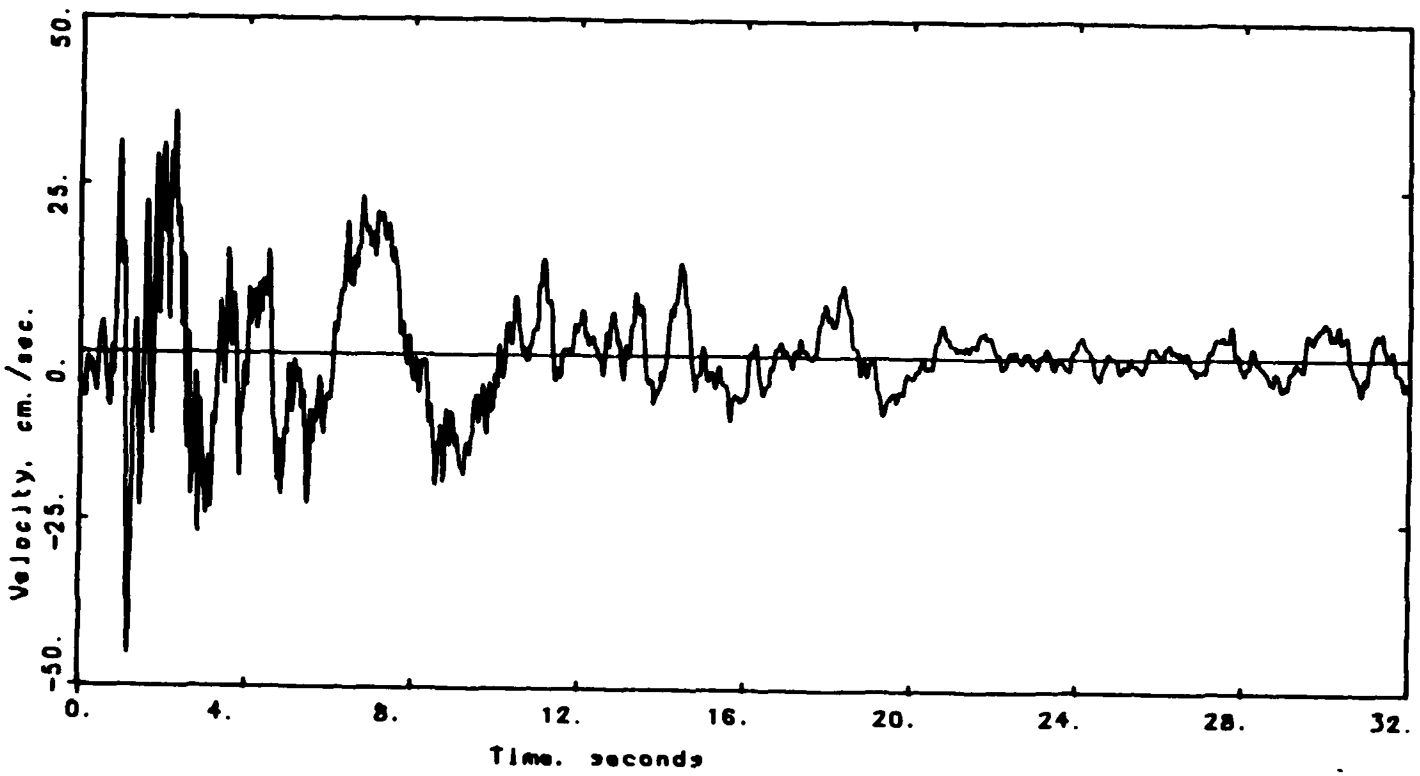
Also shown are acceleration, velocity, and displacement time histories in addition to the response spectrum for the WUS event recorded at a depth of 20 m within a 40 m thick soil site (Table 3).

Filtering (5 pole)	WUS (Hz)	EUS (Hz)
Low-Pass	23.0	40.0
High-Pass	.17	.17



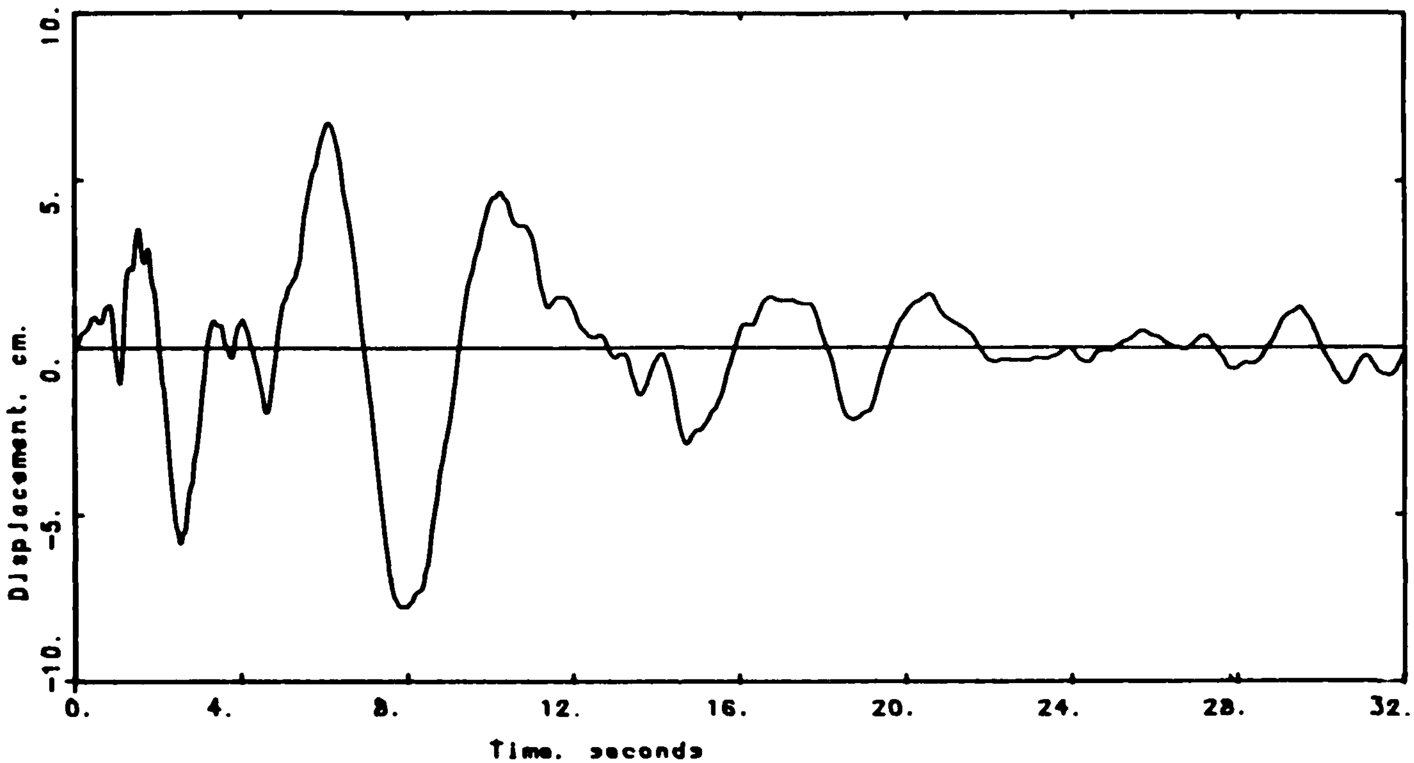
SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : Mw=7.0, R=10.0 KM.

LEGEND
—— At Rock Outcrop



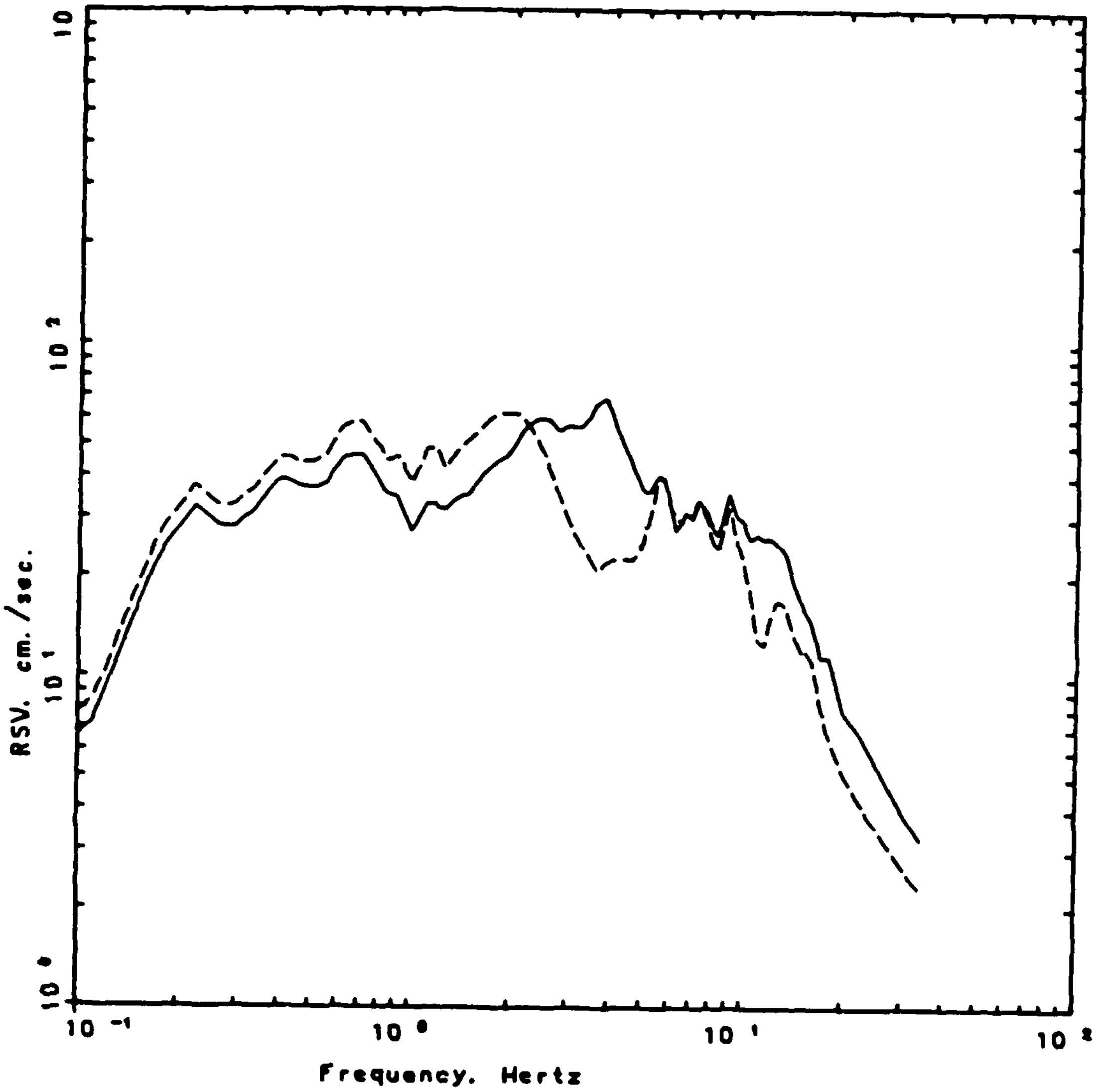
SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : Mw=7.0, R=10.0 KM.

LEGEND
—— At Rock Outcrop



SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : Mw=7.0, R=10.0 KM.

LEGEND
At Rock Outcrop

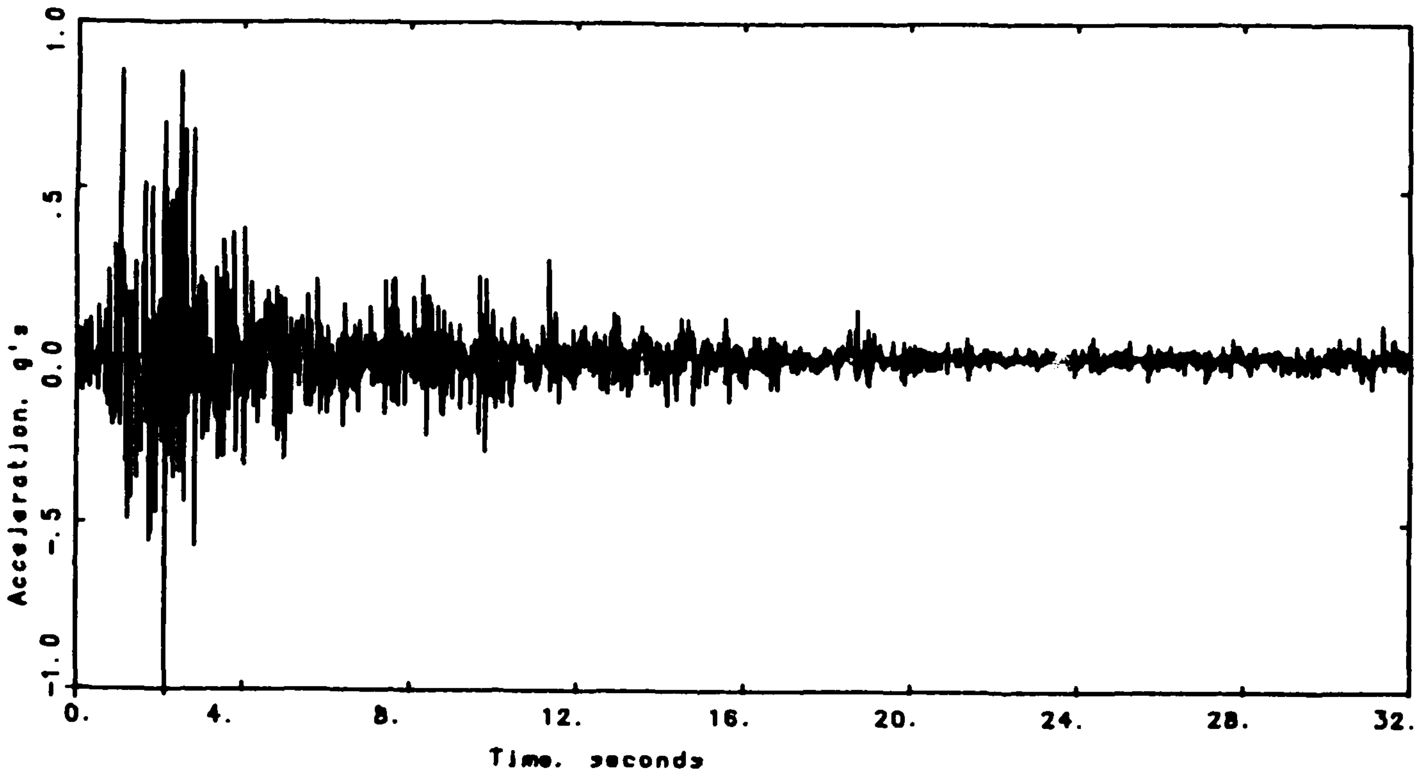


WES : WUS : RESPONSE AT ROCK OUTCROP (Mw = 7)

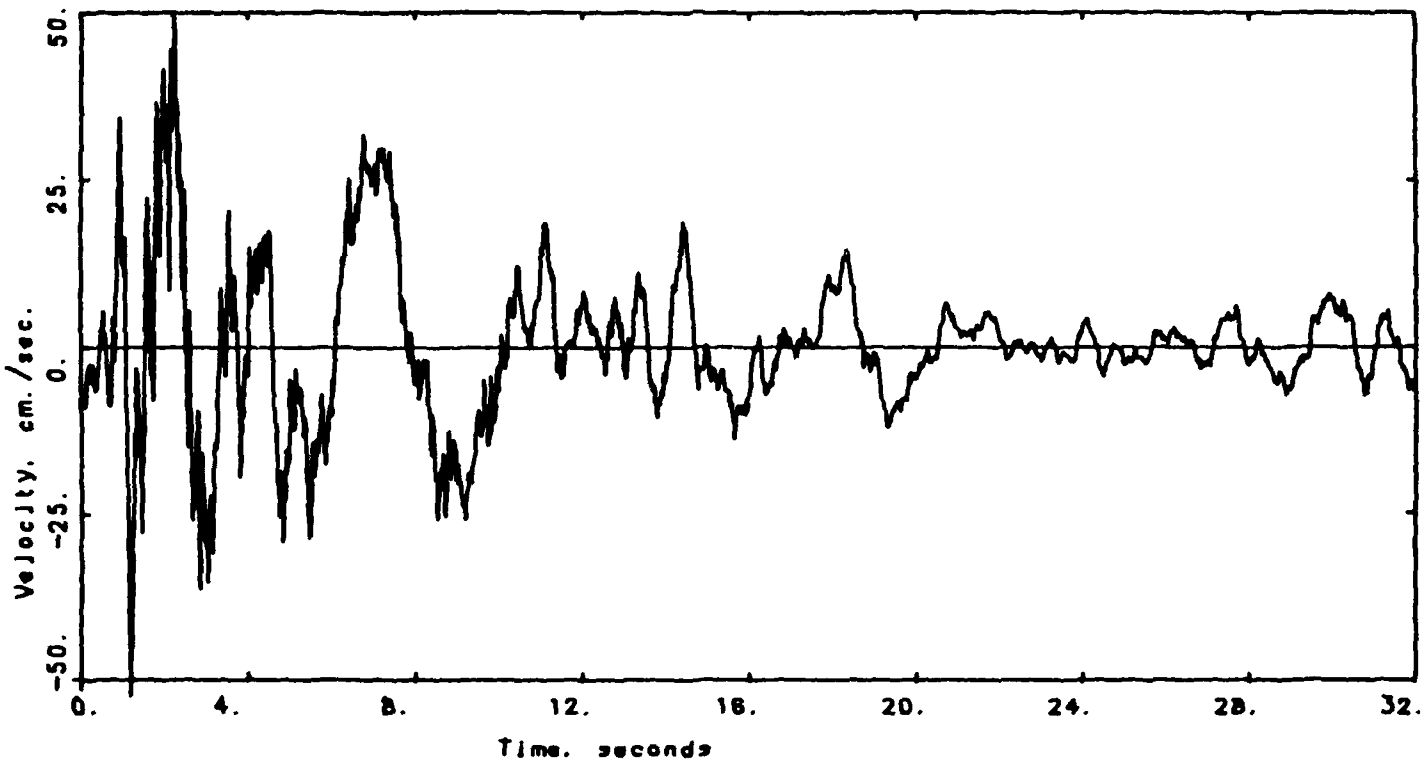
LEGEND

- - - - At 20 m.

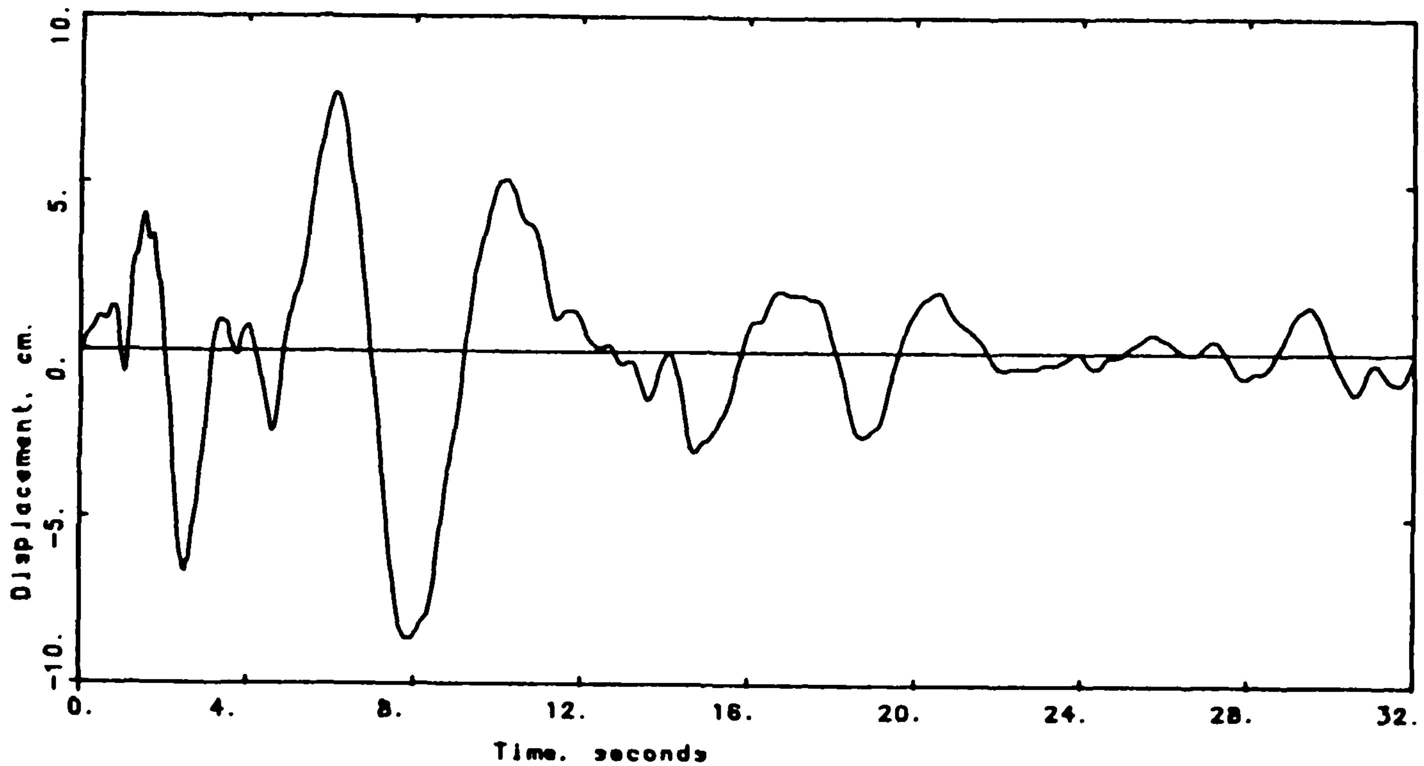
——— At Rock Outcrop



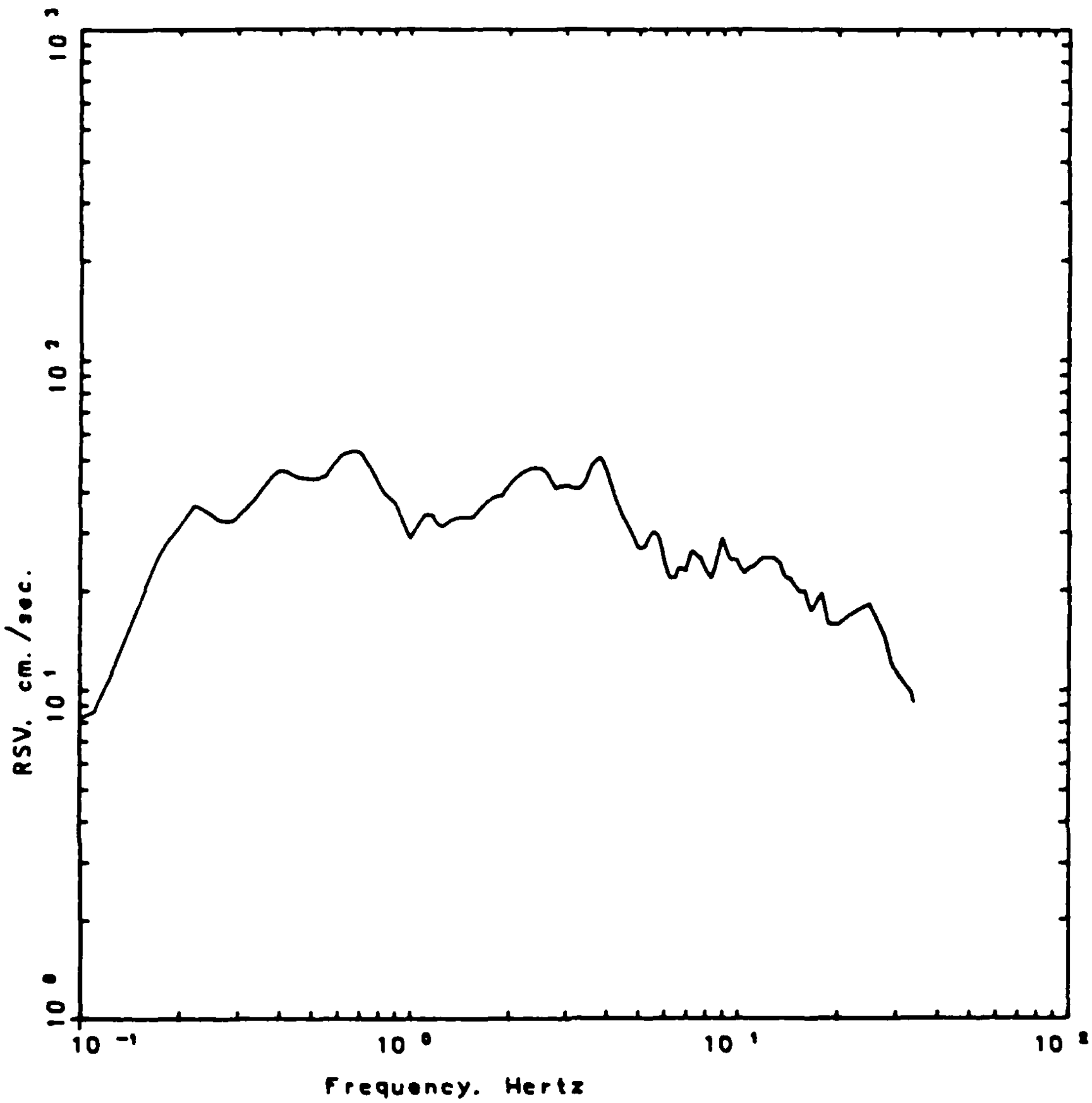
SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : mb=7.0, R=10.0 KM.



SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : mb=7.0, R=10.0 KM.

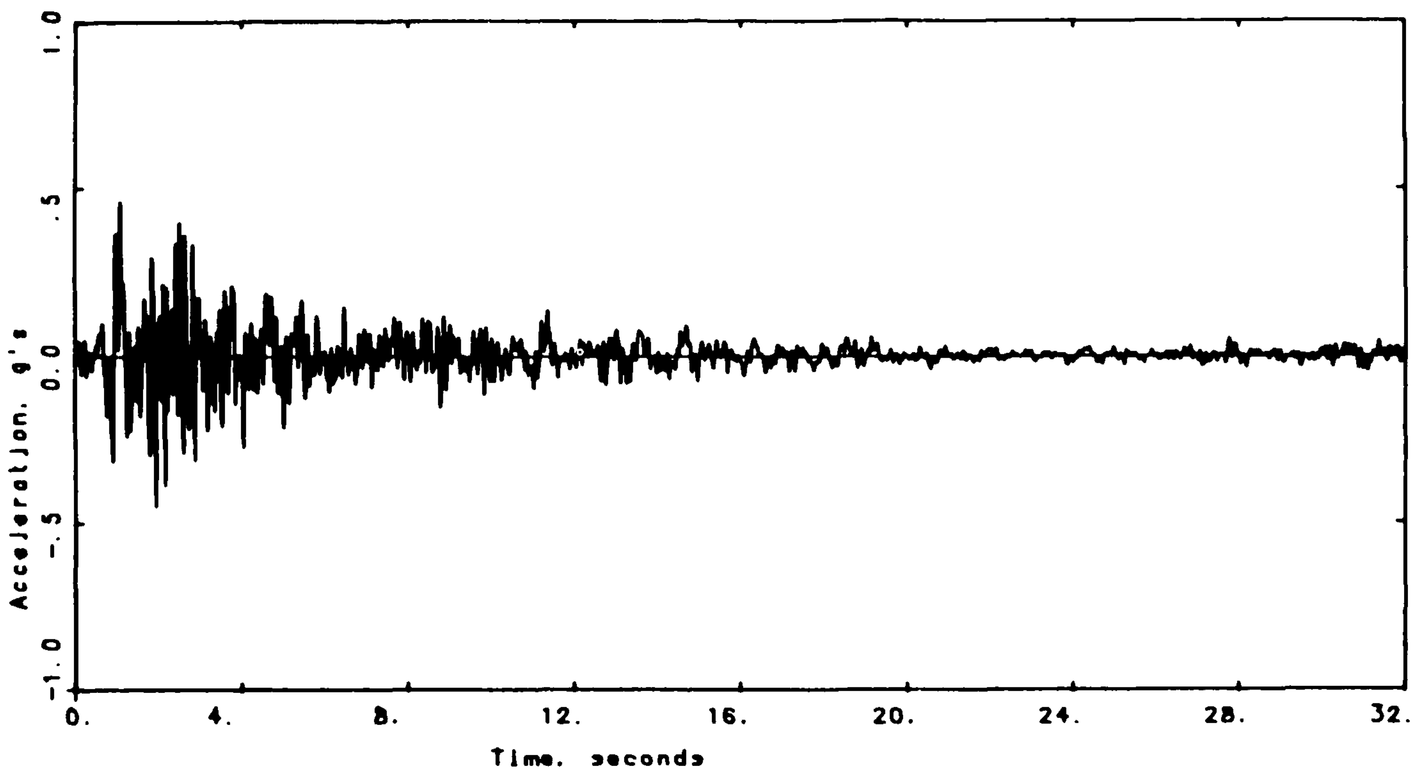


SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : mb=7.0, R=10.0 KM.



WES : EUS : RESPONSE
AT ROCK OUTCROP (mb = 7)

LEGEND
5 %

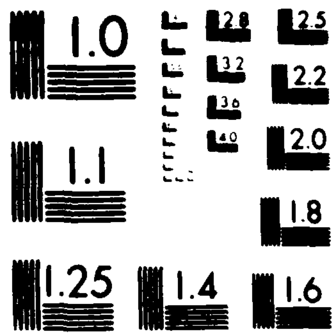


SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : Mw=7.0, R=10.0 KM.

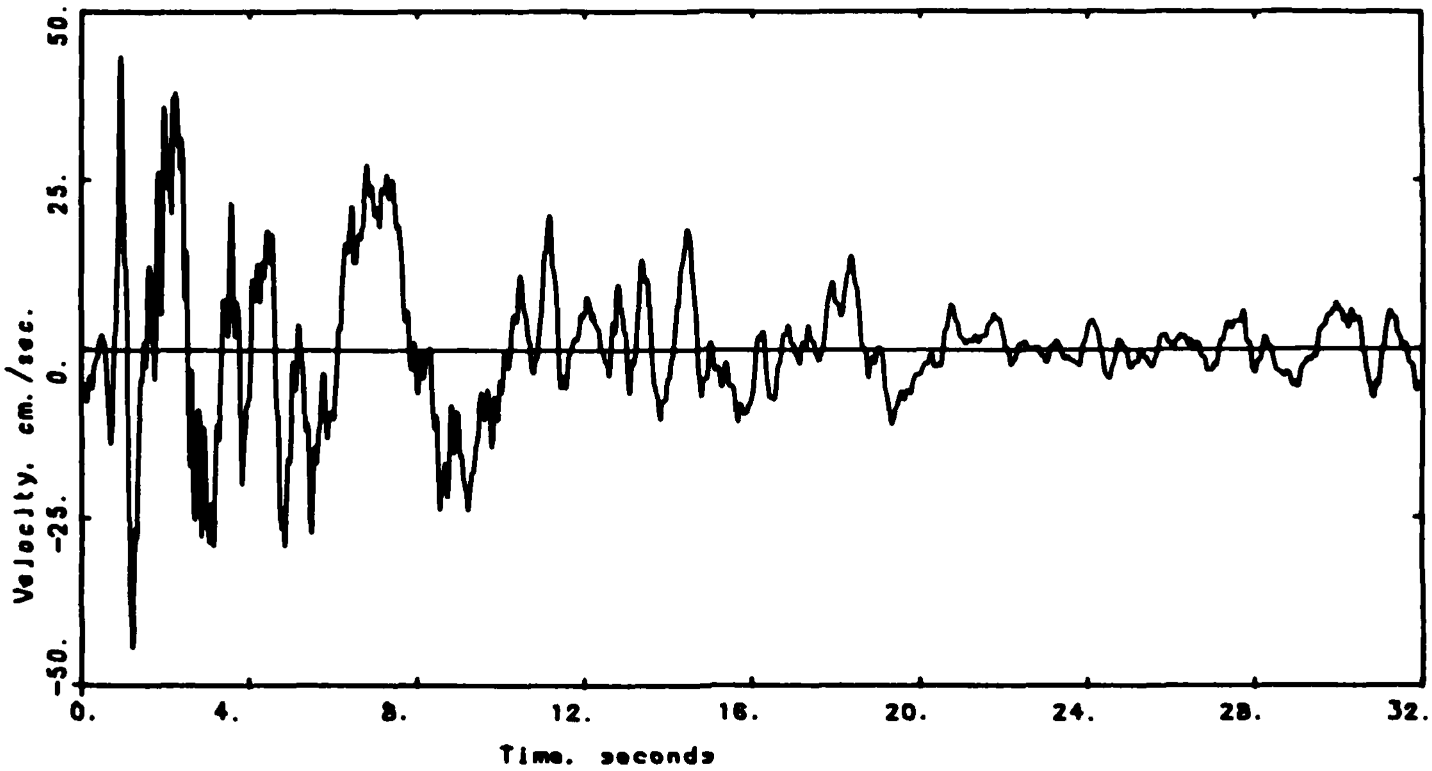
LEGEND
At 20 m.

AD-A182 901 STATE-OF-THE-ART FOR ASSESSING EARTHQUAKE HAZARDS IN THE UNITED STATES RE (U) WOODWARD-CLYDE CONSULTANTS WALNUT CREEK CA W J SILVA ET AL MAY 87 2/2

UNCLASSIFIED WES-MP-S-73-1-24 DACW39-85-M-1585 F/G 8/11 NL

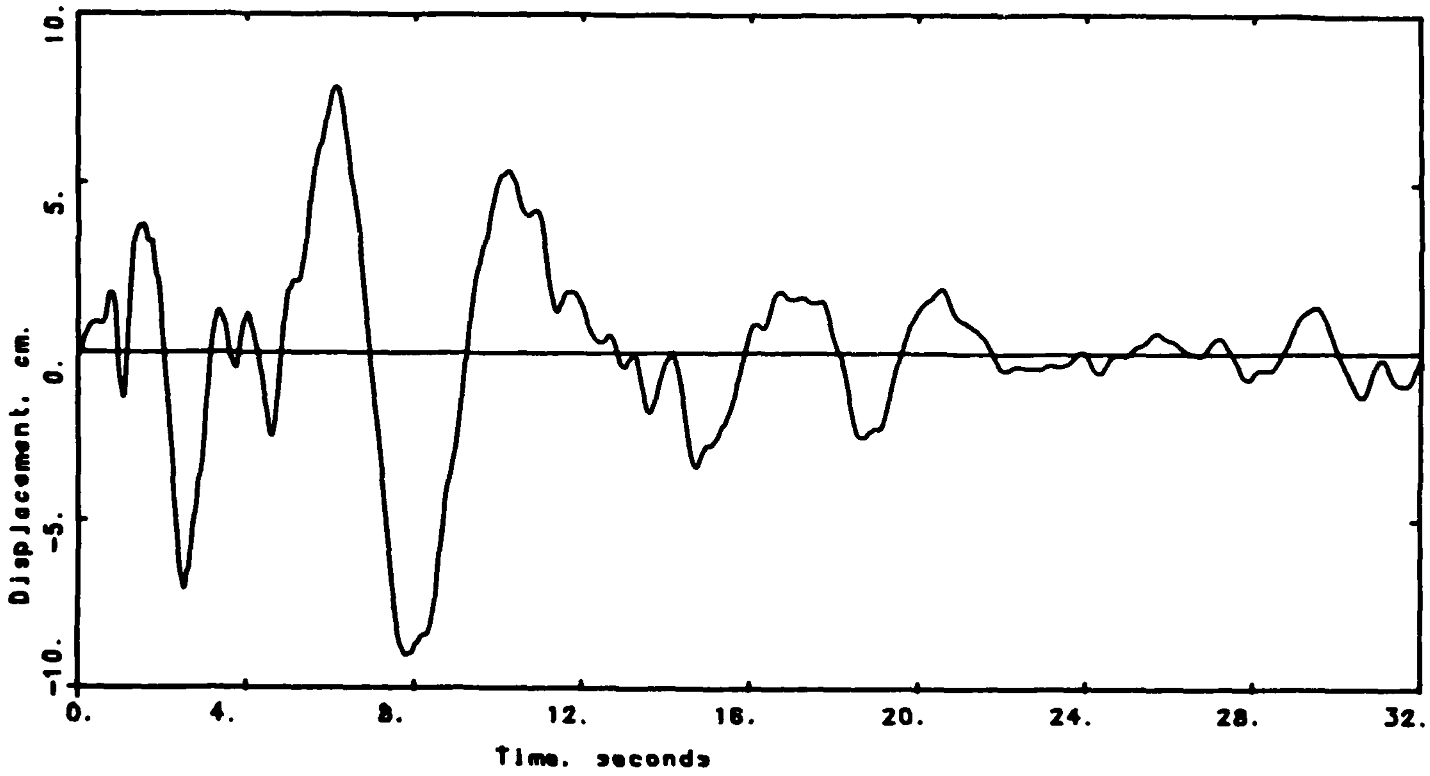


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : Mw=7.0, R=10.0 KM.

LEGEND
At 20 m.



SAN FERN., ML=6.4, R=24.5 KM.
MODULUS : Mw=7.0, R=10.0 KM.

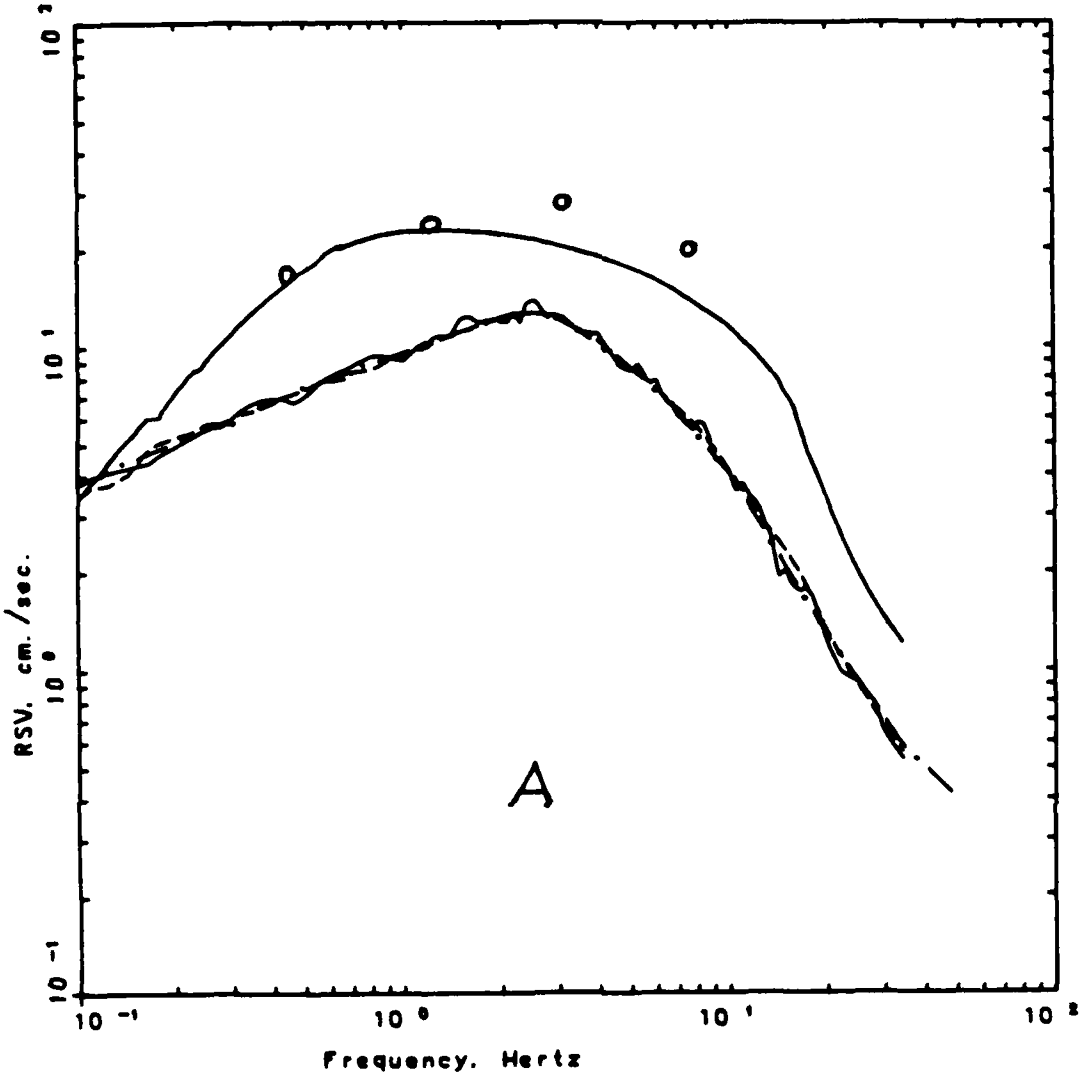
Figure Set 9. Plots of response spectral scaling results.

A) Plot or response spectra. Open circles are from Boore (1983) and represent regressions on WUS data for a moment magnitude 6 event at a closest distance of 10 km. The upper solid line is initial RVT response spectrum for a moment magnitude 6 event at a hypocentral range of 10 km. Dashed-dotted line is the specified target response spectrum scaled to 0.125 g. The dashed line is after two iterations using the RVT calculated response spectra to scale the Brune spectra. The solid lower line represents the final two iterations which employ time domain calculations of the response spectra. Time histories are calculated by adding an observed phase (from the time history library) to the scaled Brune modulus.

B) Plot of Fourier spectral density after two iterations (dotted line) and after four iterations (solid line). The first two iterations have used the RVT calculated response spectra to scale the Brune spectra. The final two iterations use time domain calculations to evaluated the response spectra.

C) Solid line shows effects of band-pass filters on response spectra. The filters are fifth order Butterworth with corners at 4 seconds (high-pass) and 23 Hz (low-pass). The filtering is done after the last iteration. Remaining curves are the same as those in plot (A).

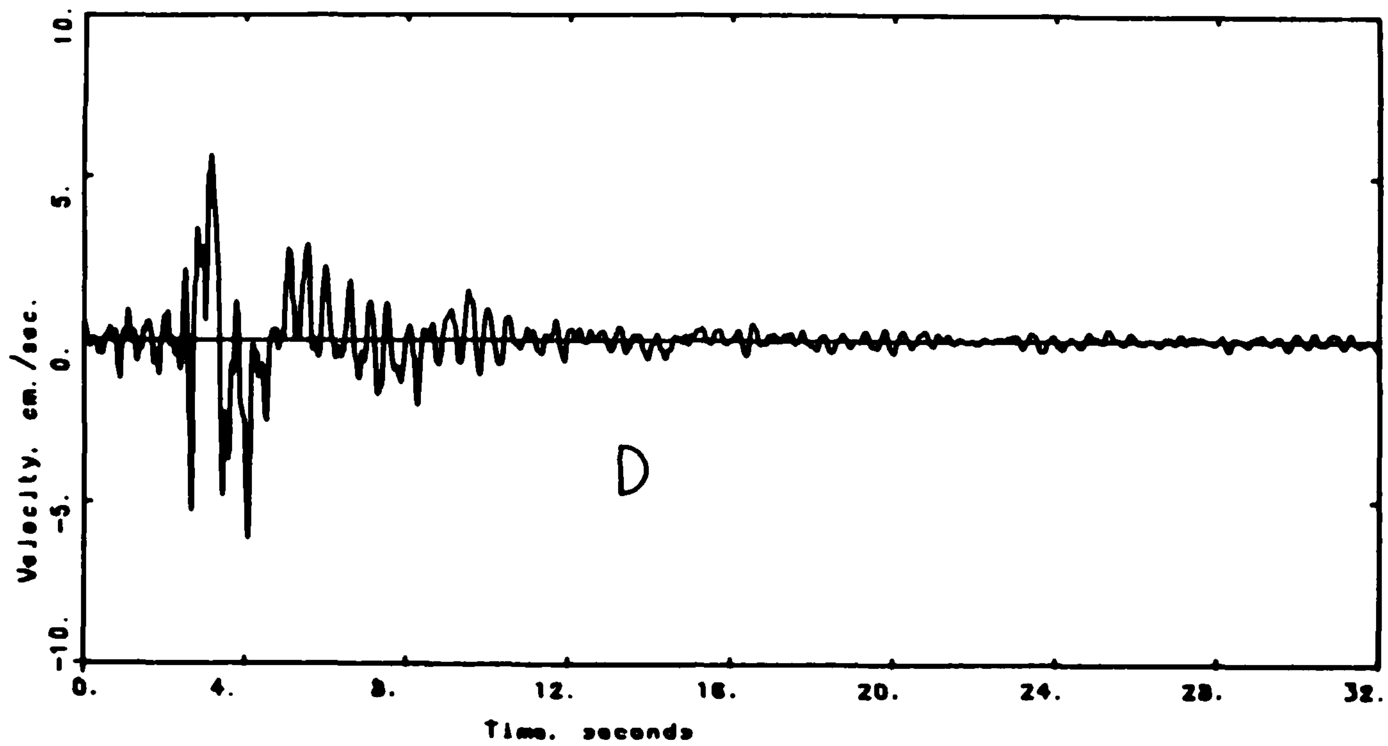
D) Resultant acceleration, velocity, and displacement time histories. The response spectra for the acceleration time history is shown in plot (C) solid line. Unnormalized peak acceleration is 0.116 g.



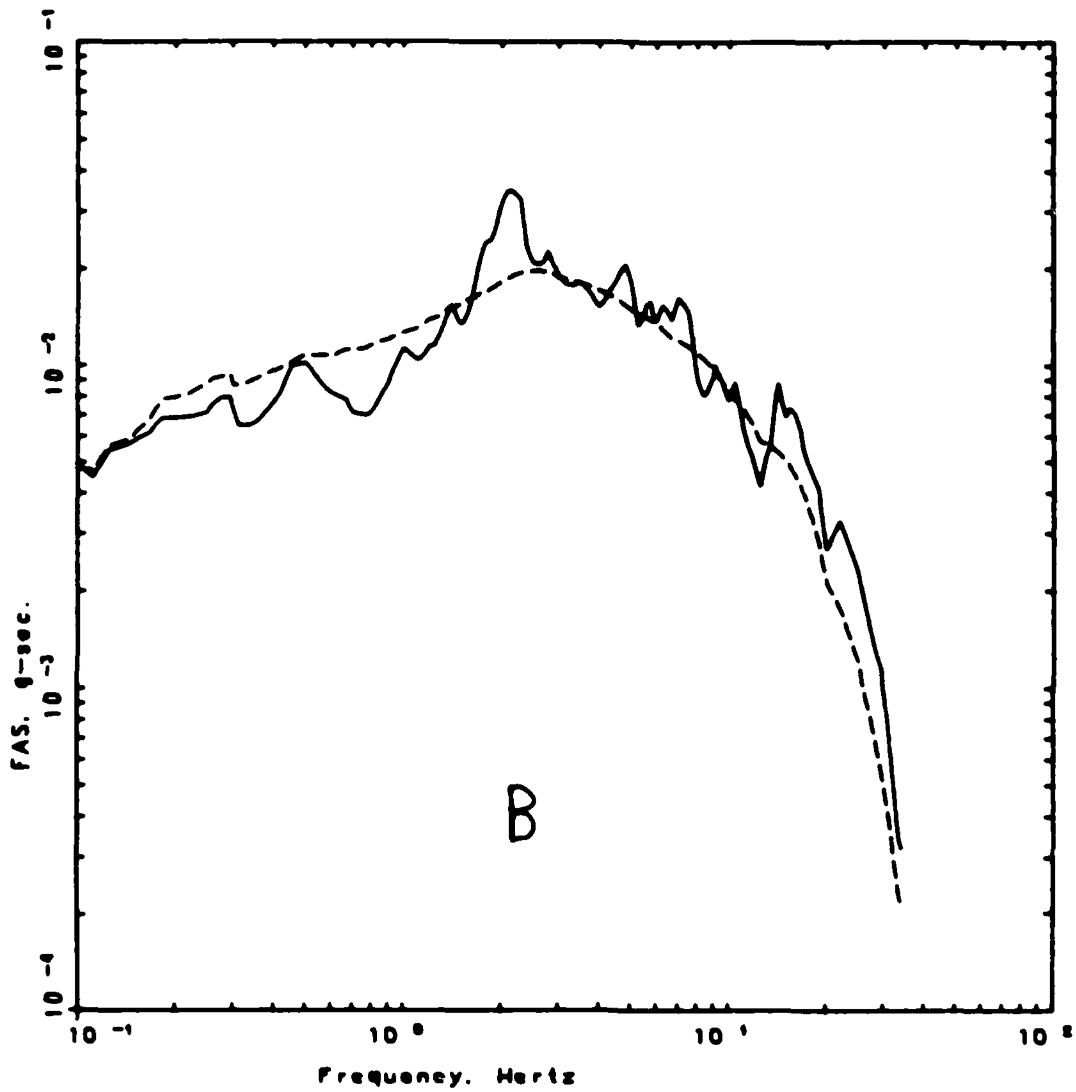
WES : RESPONSE SPECTRA
AT ROCK OUTCROP (Mw = 6)

LEGEND

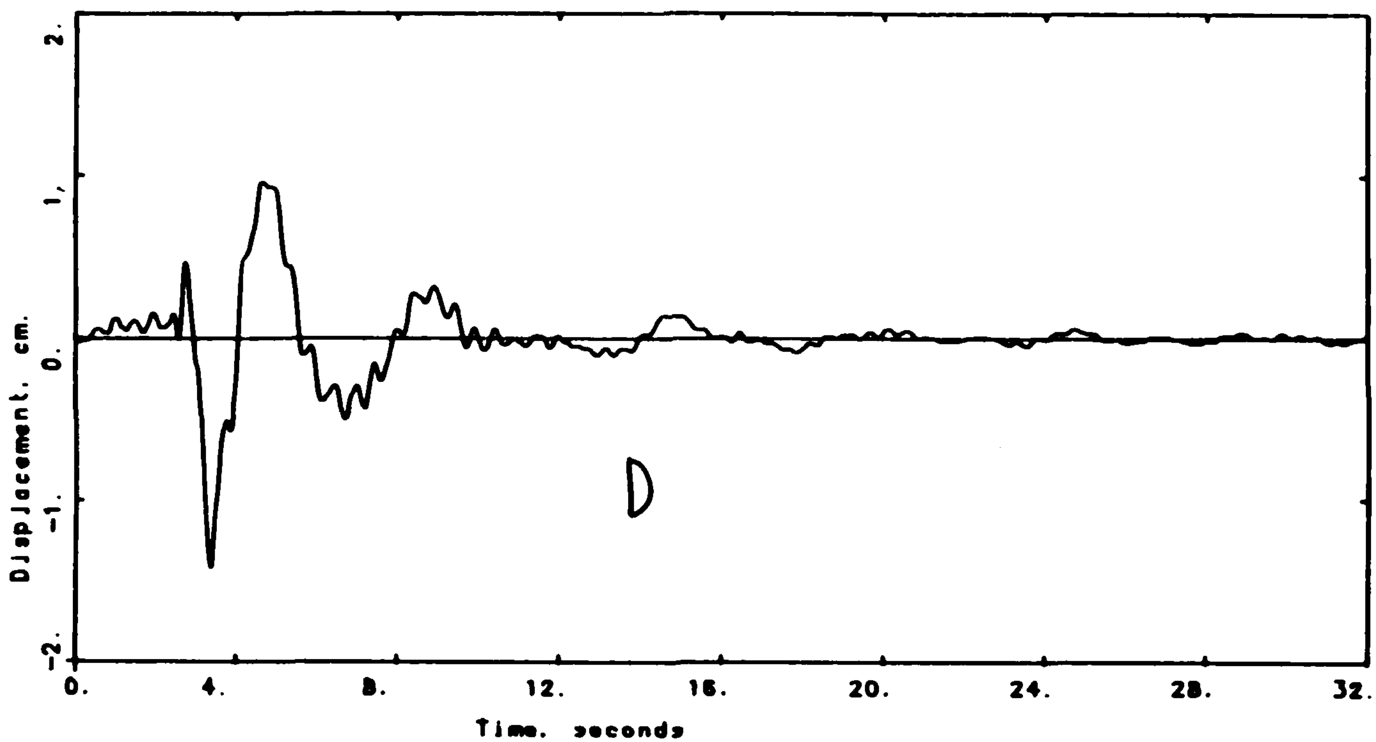
— · — Design Spectrum (Amax = 0.125 g). 5 % damping



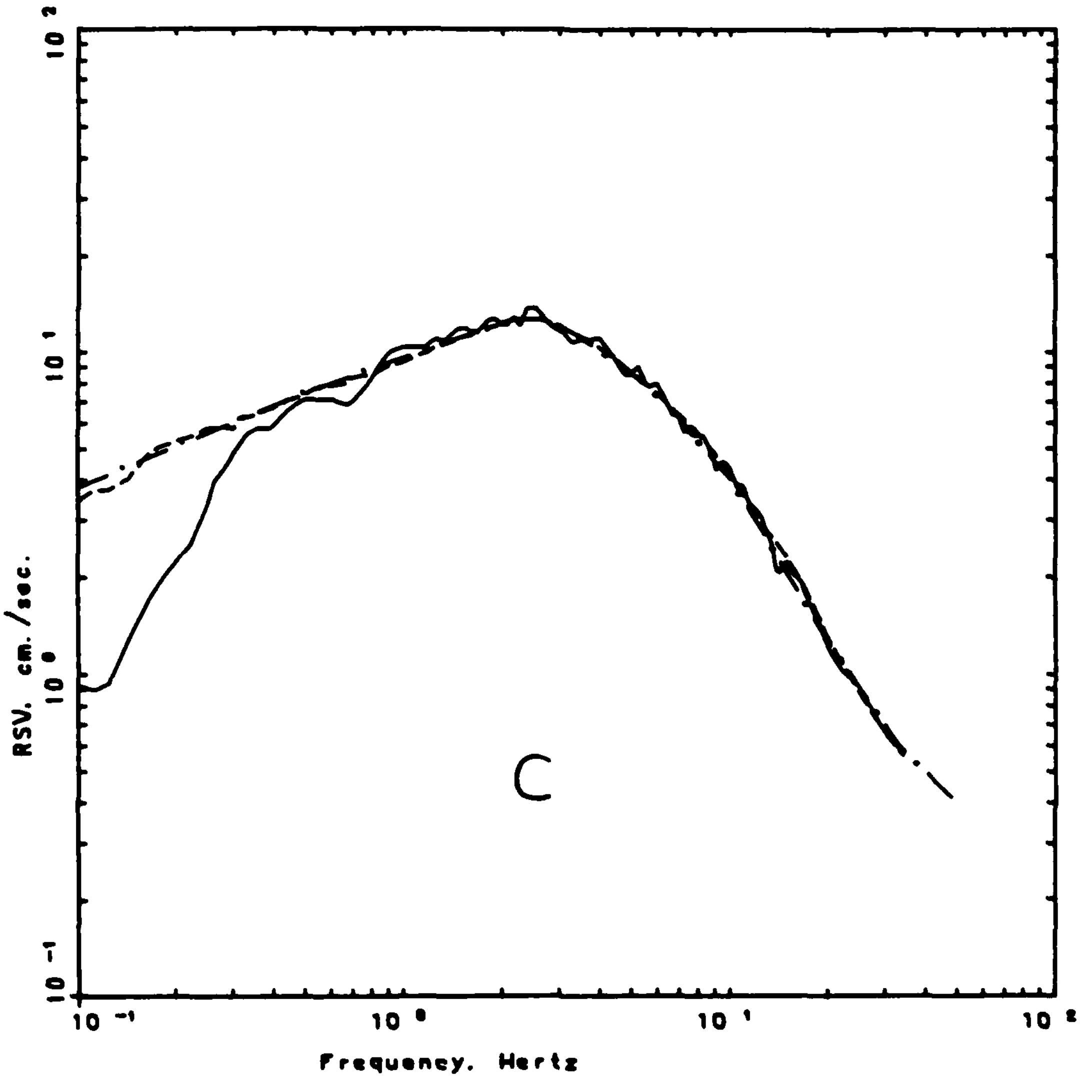
COYOTE : ML=5.9, R=18.7 KM.
MODULUS : MW=6.0, R=10.0 KM.



WES : FOURIER SPECTRA
AT ROCK OUTCROP (Mw = 6)



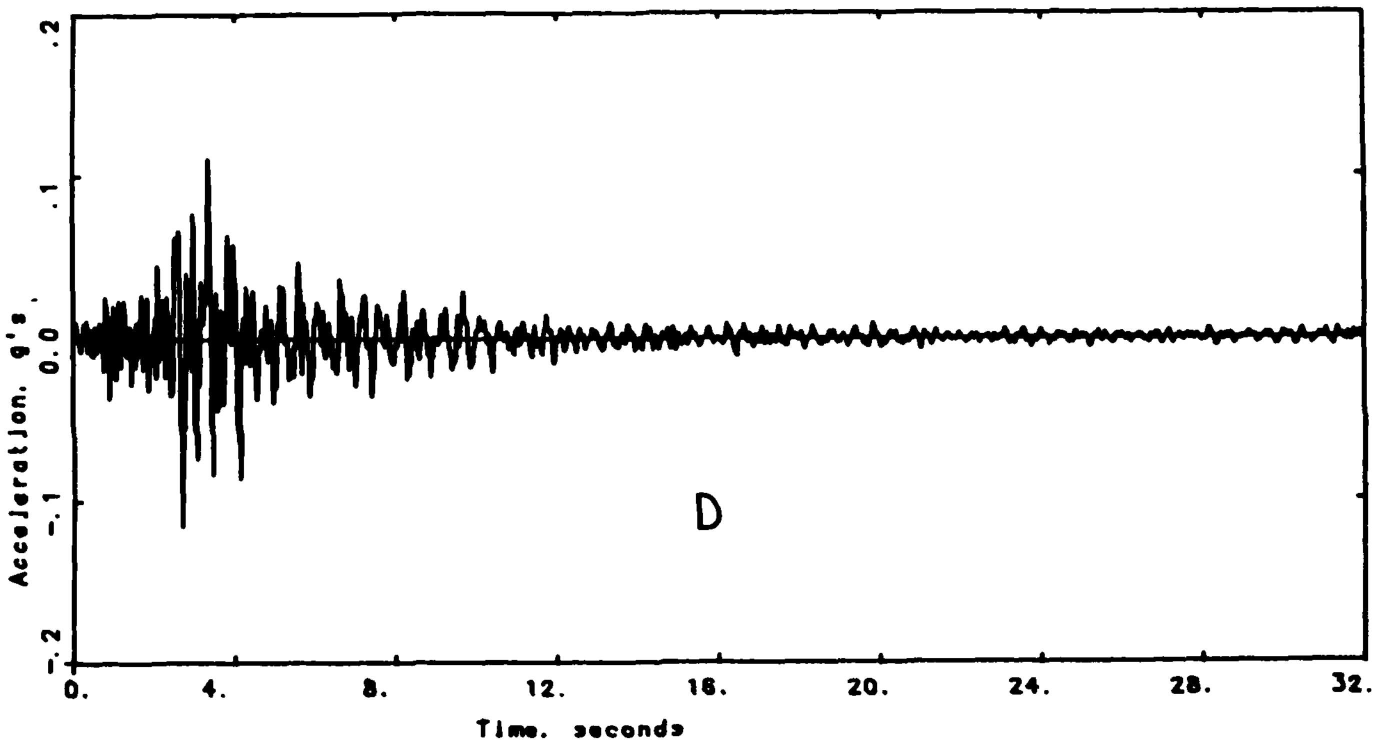
COYOTE : ML=5.9, R=18.7 KM.
MODULUS : MW=6.0, R=10.0 KM.



WES : RESPONSE SPECTRA
AT ROCK OUTCROP (Mw = 6)

LEGEND

—·— Design Spectrum (Amax = 0.125 g), 5 % damping

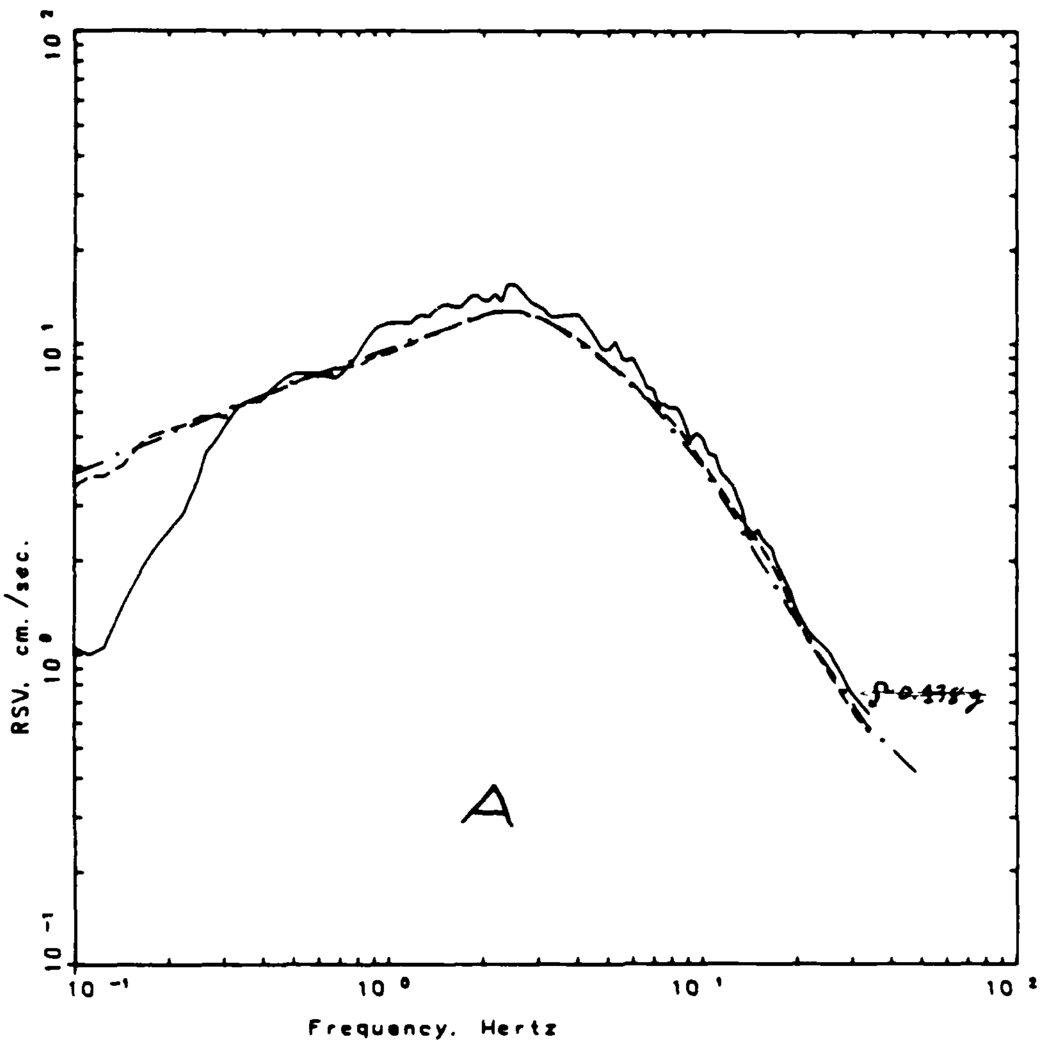


COYOTE : ML=5.9, R=18.7 KM.
MODULUS : MW=6.0, R=10.0 KM.

Figure Set 10. Plots of response spectra and acceleration time history normalized to design value of 0.125 g.

A) solid line is the time domain calculated response spectra of the normalized acceleration time history. Remaining curves are the target response spectra (dashed-dotted) and the second iteration RVT response spectra (dotted).

B) Acceleration time history normalized to 0.125 g.



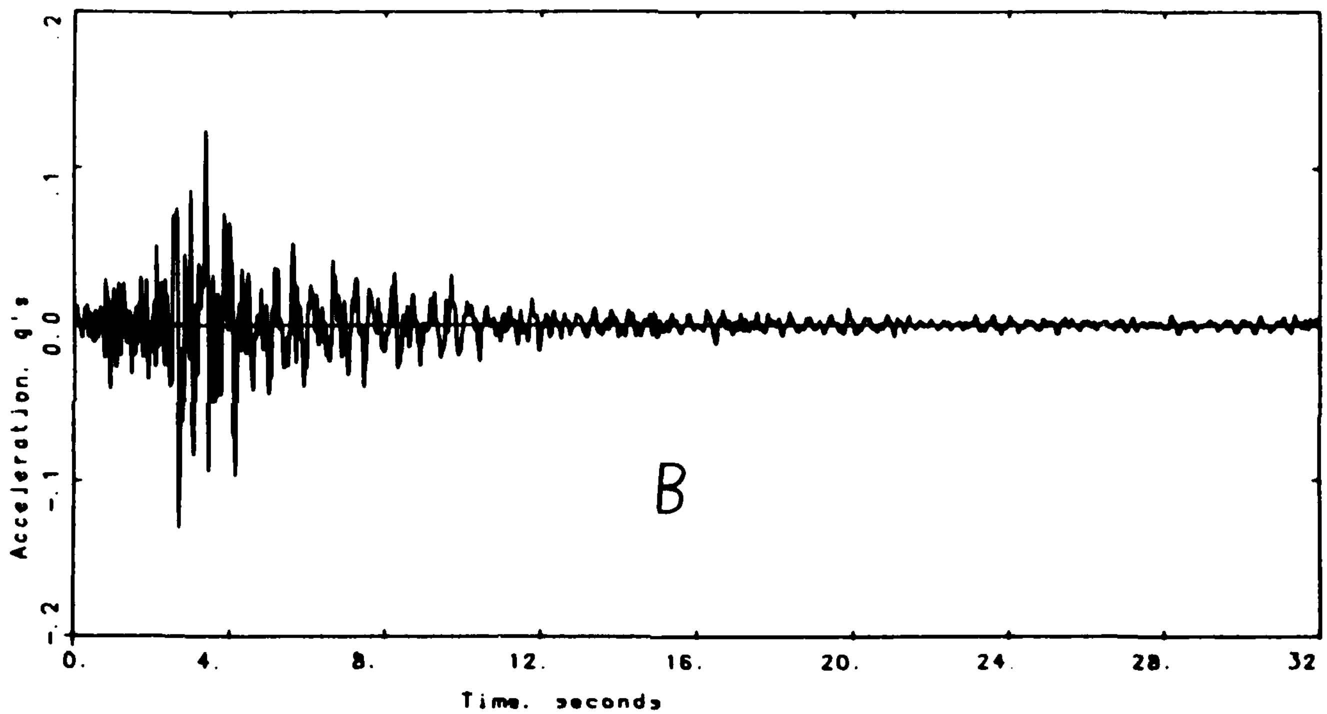
WES : RESPONSE SPECTRA MA
AT ROCK OUTCROP (Mw = 6)

LEGEND

— · — Design Spectrum (Amax = 0.125 g). 5 % damping

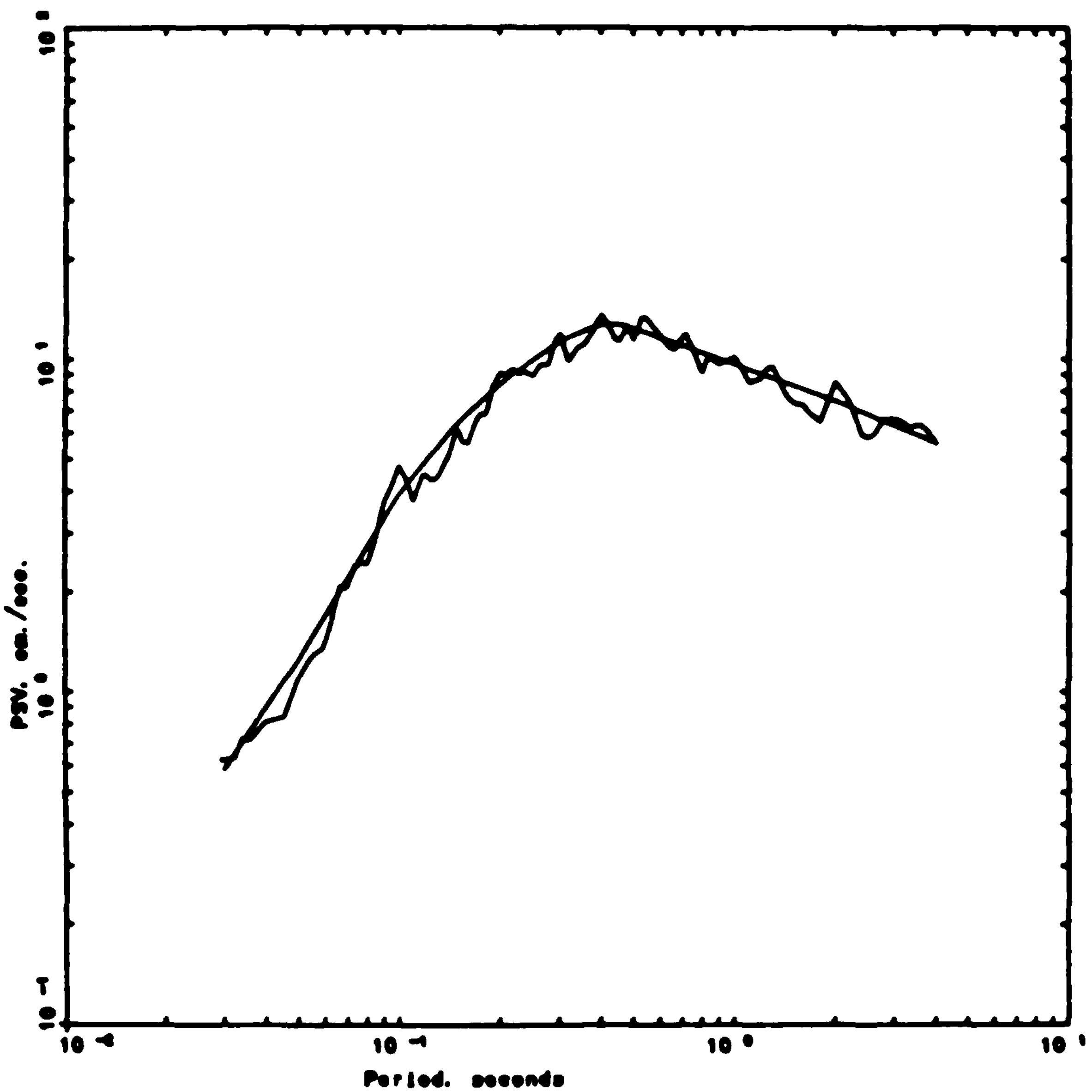
- - - - Computed RVT Spectrum (2 Iterations). 5 % damping

——— Computed SDF Spectrum (4 Iterations). 5 % damping



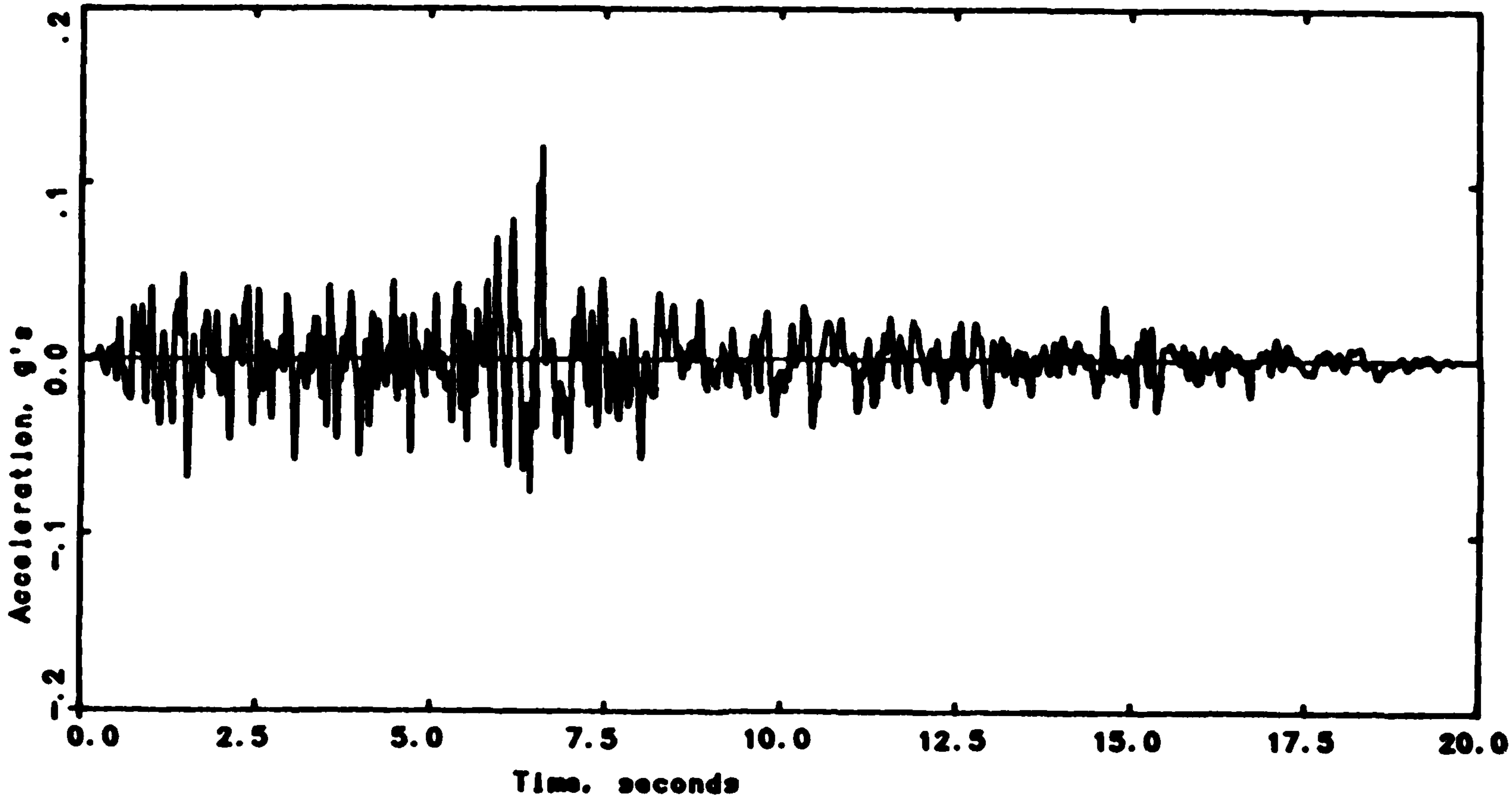
COYOTE : ML=5.9, R=18.7 KM.
MODULUS : MW=6.0, R=10.0 KM.

Figure Set 11. Plots of results from a different scaling technique fitted to the same target response spectra. Target and final response spectra along with acceleration, velocity, and displacement time histories are shown.

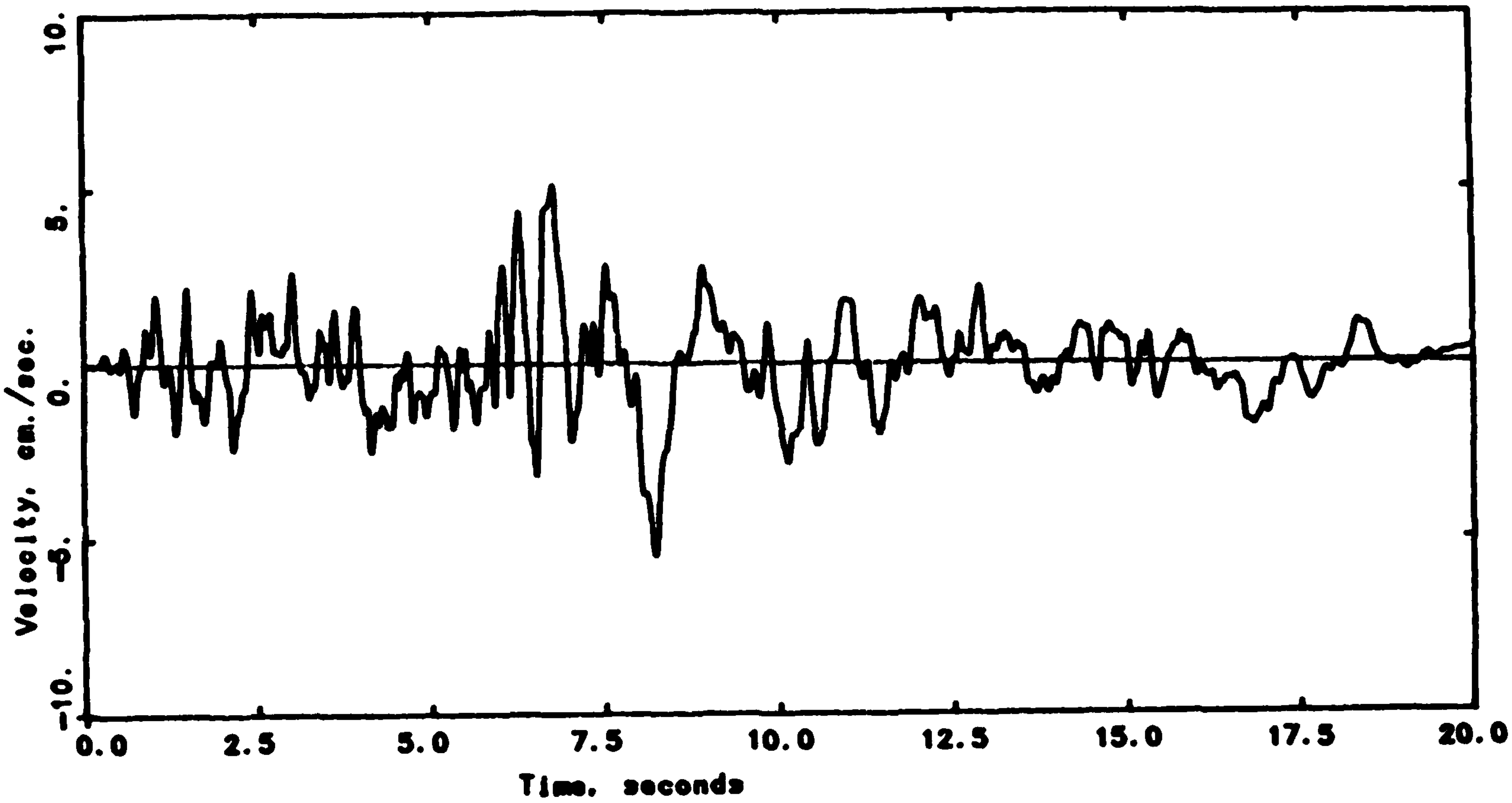


VAFB : DESIGN SPECTRA

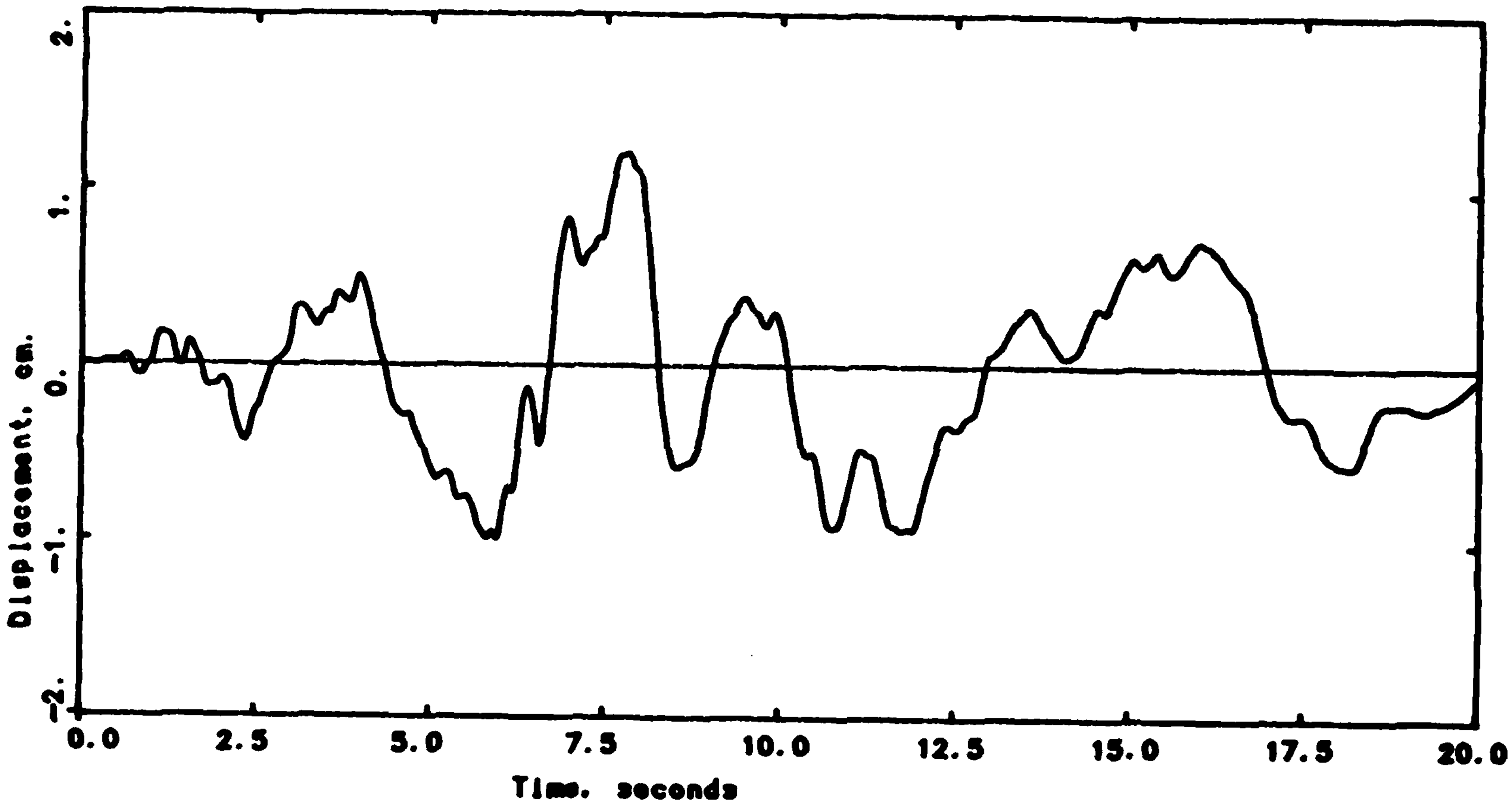
LEGEND
Design Spectrum (Amax = 0.125 g), 5 % damping
5 % BASELINE CORRECTED



VAFB : MODIFIED ACCEL. T. H.

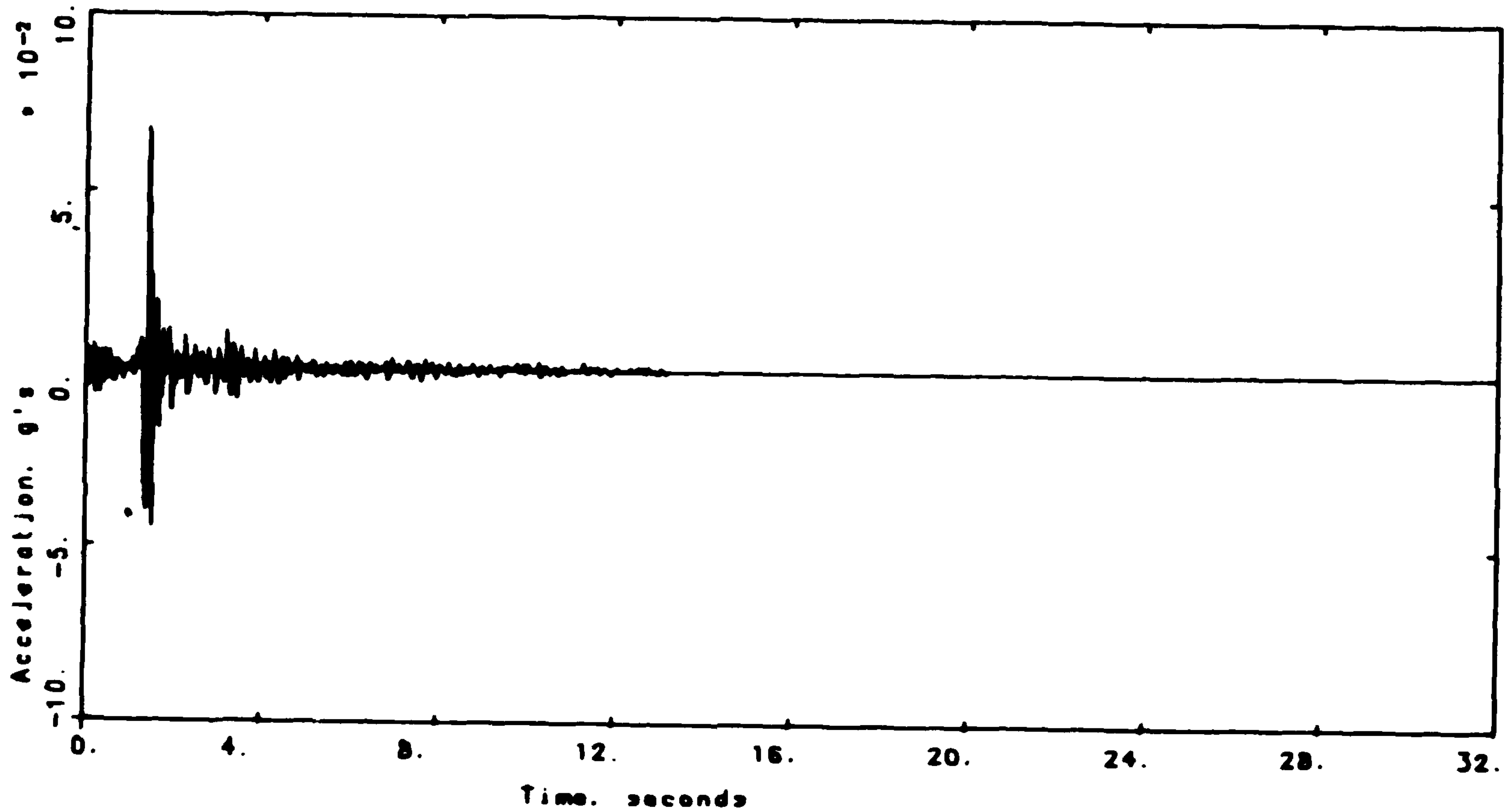


VAFB : MODIFIED VELOCITY T. H.

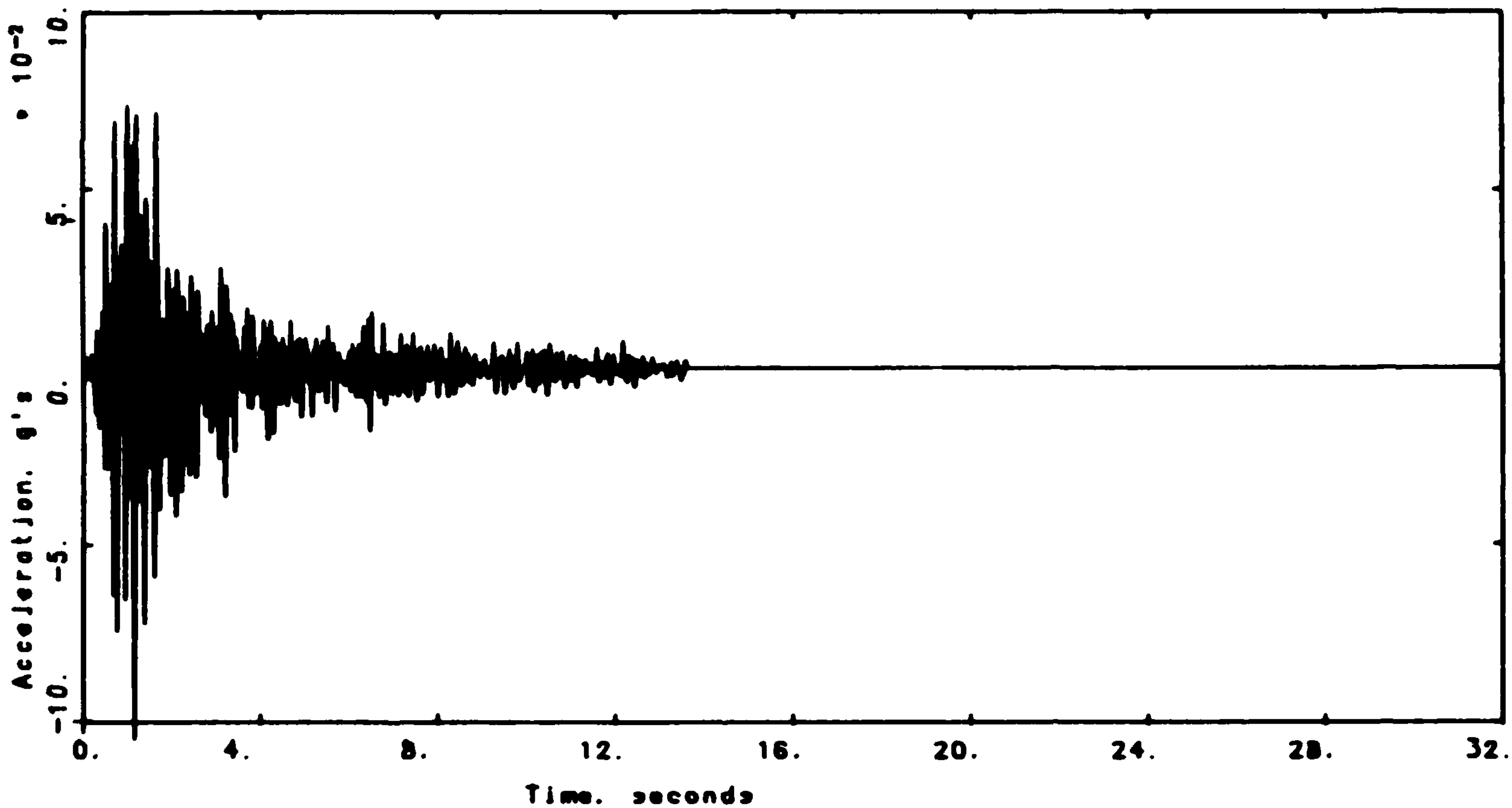


VAFB : MODIFIED DISPL. T. H.

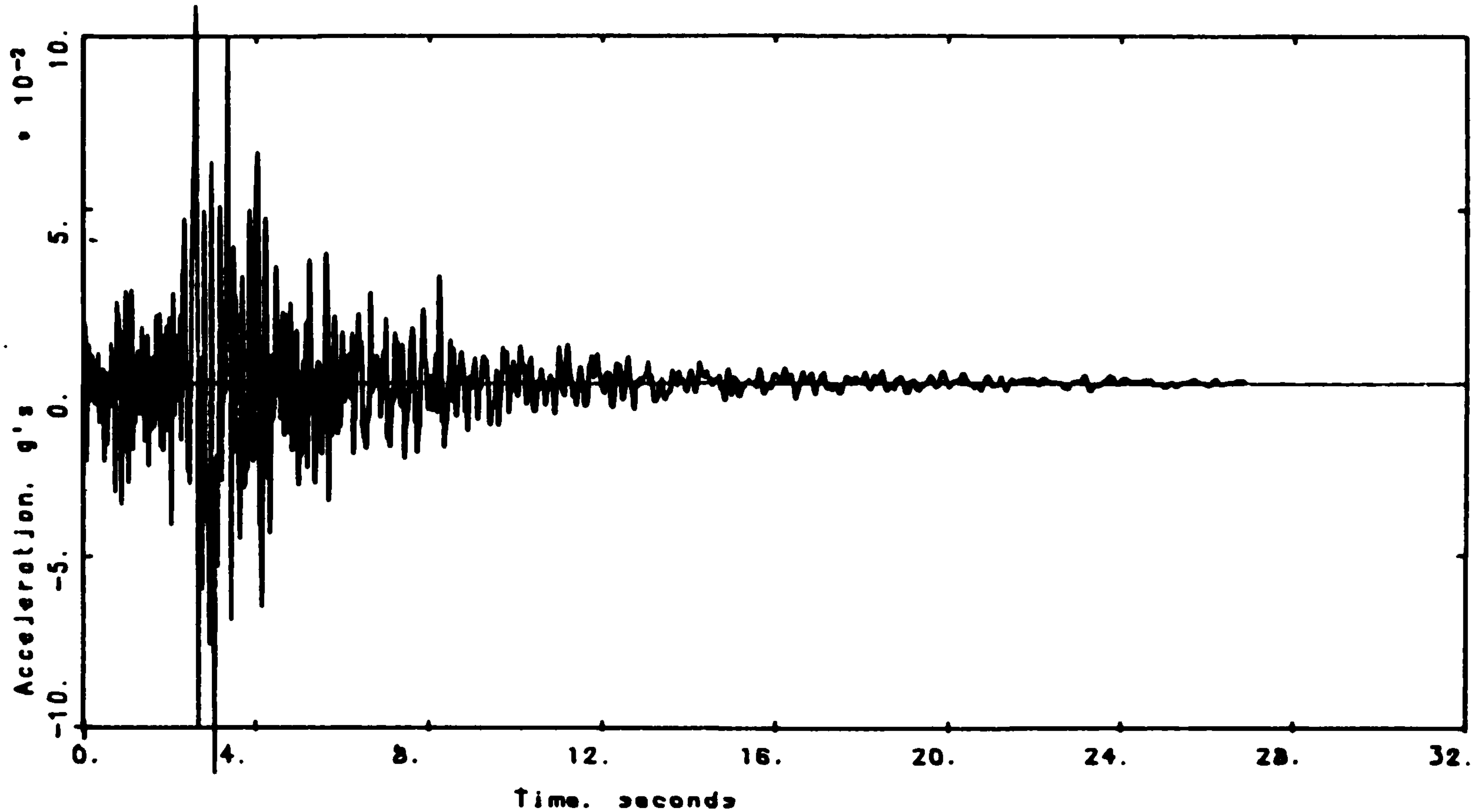
Figure Set 12. Plots of basis time histories which are used to supply phases to the Brune spectrums. Magnitude range and distance range criterion for matching to the Brune spectra are given in Table 4.



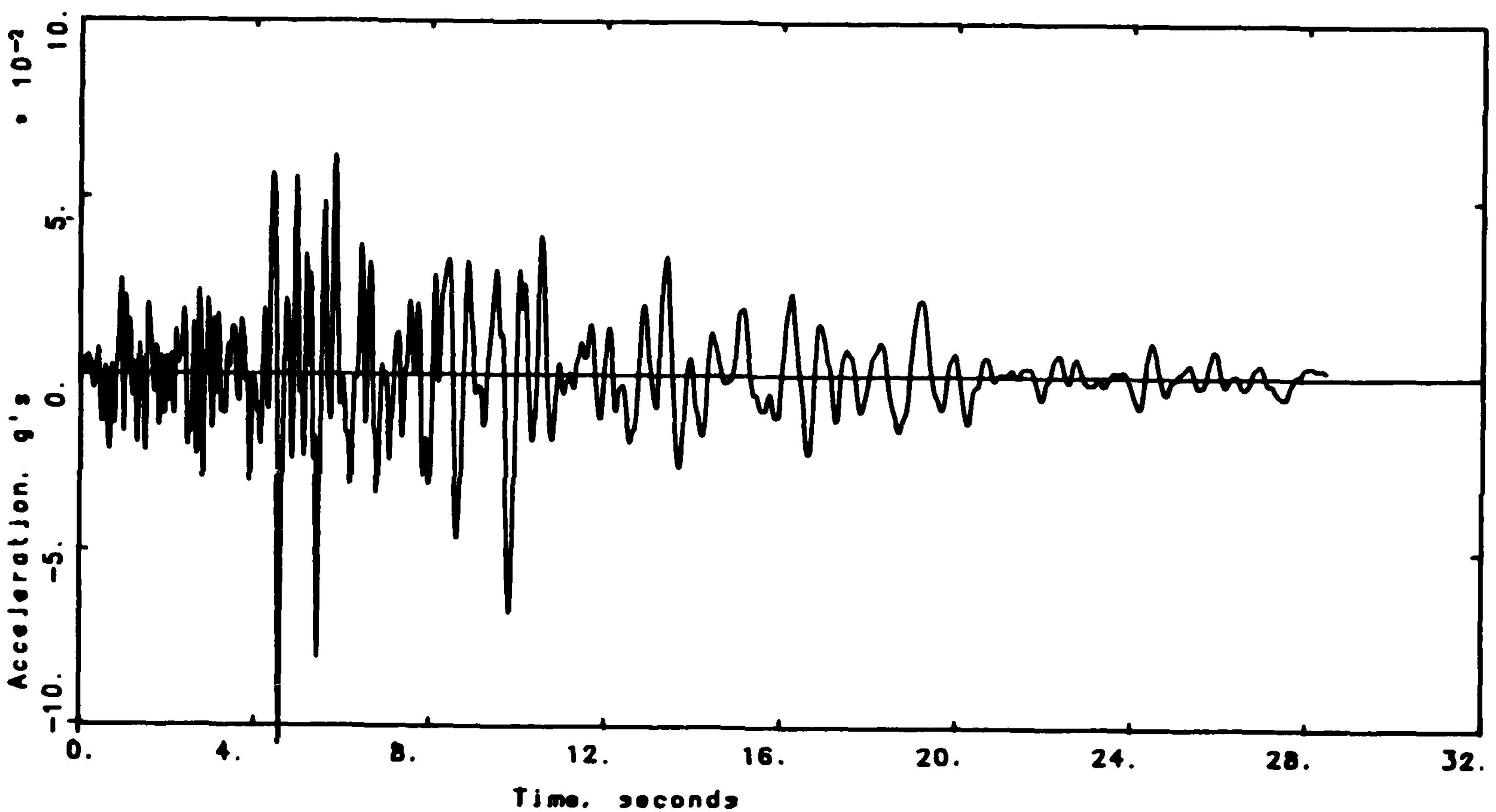
OROVILLE AFTERSHOCK, 1975
ML = 4.0, R = 10.5 KM.



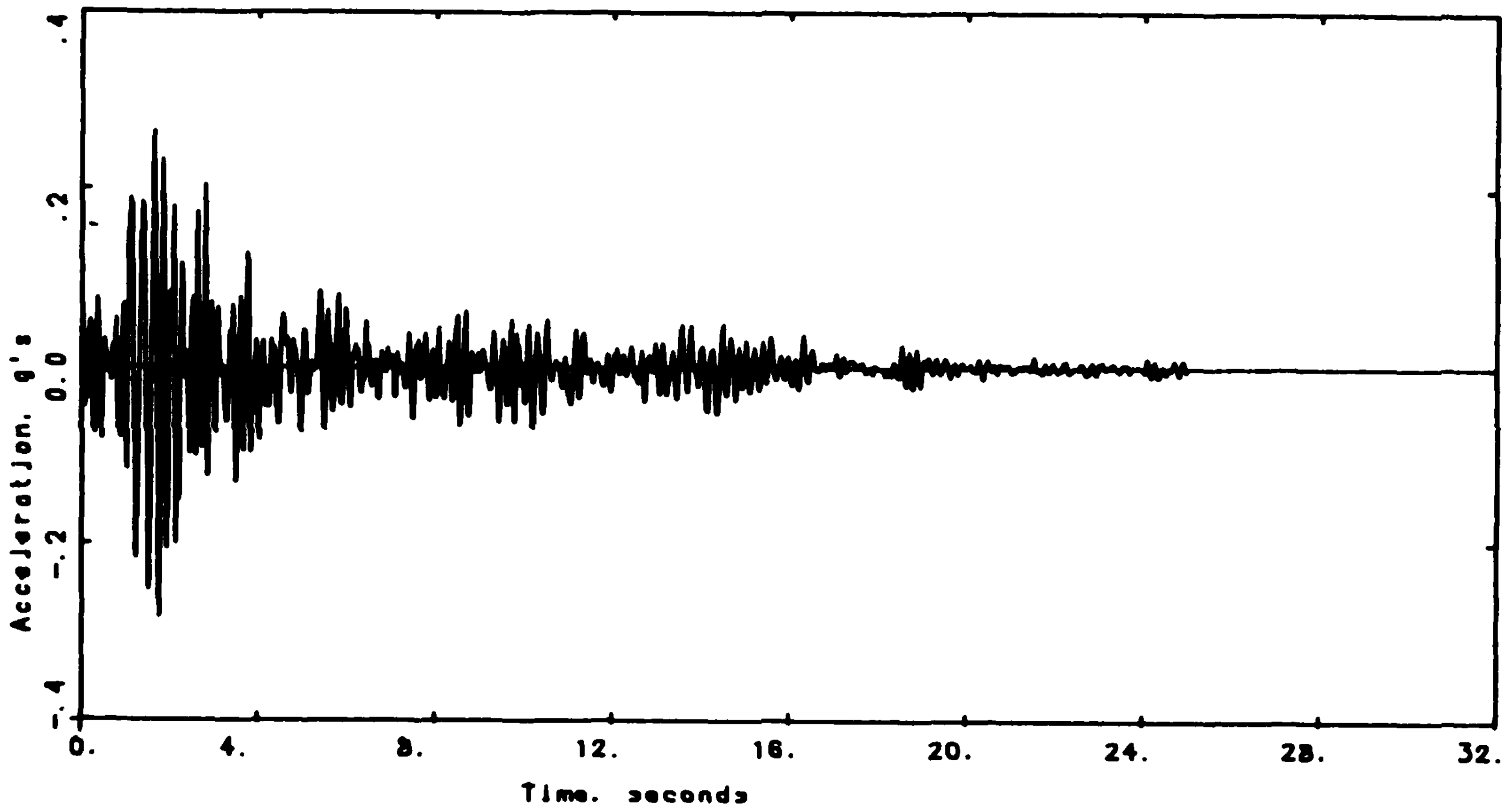
OROVILLE AFTERSHOCK, 1975
ML = 4.9, R = 8.6 KM.



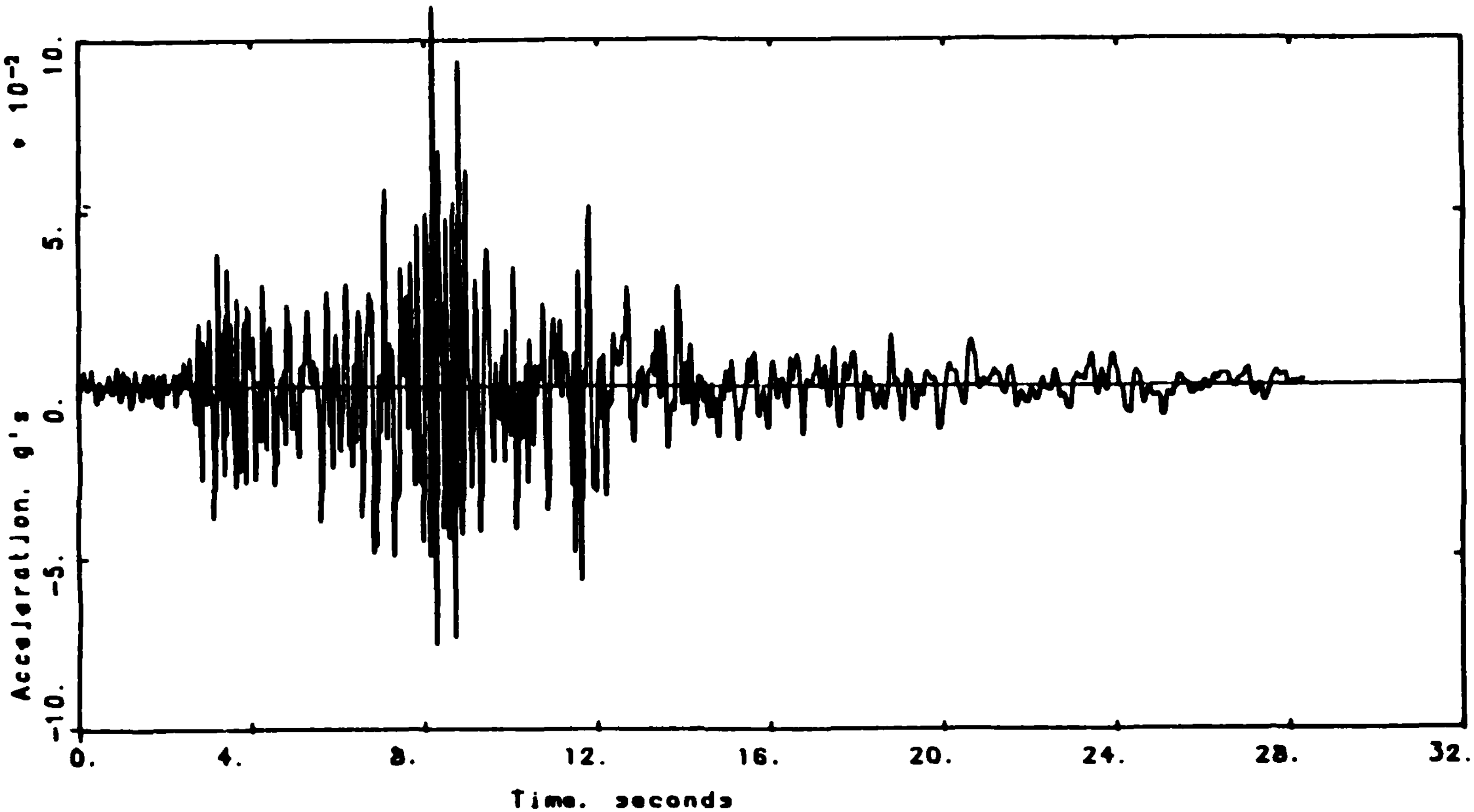
COYOTE LAKE, MAIN SHOCK, 1979
ML = 5.9, R = 18.7 KM.



COYOTE LAKE, MAIN SHOCK, 1979
ML = 5.9, R = 29.4 KM.



SAN FERNANDO MAIN SHOCK, 1971
ML = 6.4, R = 24.5 KM.



IMPERIAL VALLEY, MAIN, 1979
ML = 6.6, R = 40.0 KM.

END

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